Do Young People's Executive Functioning Capabilities Impact Their Ability to Apportion Effort During a High Intensity Intermittent Running Task?

Anna Young Hunter

Submitted for the degree of Master of Philosophy

Heriot-Watt University

School of Social Sciences

September 2019

ABSTRACT

Recent studies have investigated a potential link between an invasion games (e.g. rugby, football, field hockey) players executive functioning (EF) capabilities and their performance on the pitch (Verburgh, Scherder, van Lange, Oosterlaan, & Perales, 2014; Vestberg, Gustafson, Maurex, Ingvar, & Petrovic, 2012). These studies have suggested that a player's EF might be-able to predict on-field ability. To date no studies have investigated whether EF impacts an invasion games player's ability to plan and distribute effort during a high intensity intermittent running task. Furthermore, previous studies on EF and sporting performance have exclusively used adults as their sample population with no research conducted in youth athletes. Here, I evaluated a link between a youth players EF capability and their ability to plan and distribute effort during an intermittent high intensity running task. A secondary aim of the thesis was to assess whether the addition of external feedback influenced how a young person paces during a high intensity intermittent running task. Participants' performance was assessed via physiological and psychological measures. During the physiological tasks, players were required to complete the YYIR1 test, which provided a target speed for the subsequent running tasks. The high intensity intermittent running task was 10 minutes in length. The psychological task required players to complete the Iowa Gambling Task, which is a card game that assesses EF ability. Forty-four players participated in the study with thirty-two full data sets collected (age: 14.68 ± 0.8) The results demonstrated that participants EF score did not correlate with how well players paced during the high intensity intermittent running task. However, the study did show that participants pacing ability was significantly greater when external feedback was present and one piece of feedback early on in a task is just as effective as continuous feedback. This study suggests using external feedback during intermittent high intensity exercise is effective with youth players. It also seems to suggest EF may not be related too pacing performance. However, further research is required. Reasons for this finding are discussed in the context of finding the most appreciate test of EF and definitional issues of EF

AKNOWLEDGEMENTS

Firstly, I would like to express my thanks to all my supervisors, particularly to Gnanathusharan Rajendran for always being on hand for extra advice and encouragement.

I would also like to thank my family and friends for being very helpful and supportive throughout this process.

Also, a special thanks to all those that took part in my research: Fettes College, Rangers Girls FC and Currie Rugby Club. Without their participation this thesis would not have been possible.

Research Thesis Submission

Please note this form should be bound into the submitted thesis.

Name*:*	Anna Young Hunter		
School:	School of Social Sciences		
Version: *(i.e. First, Resubmission, Final)*	Final	Degree Sought:	Master of Philosophy

Declaration

In accordance with the appropriate regulations I hereby submit my thesis and I declare that:

1. The thesis embodies the results of my own work and has been composed by myself
2. Where appropriate, I have made acknowledgement of the work of others
3. The thesis is the correct version for submission and is the same version as any electronic versions submitted*.
4. My thesis for the award referred to, deposited in the Heriot-Watt University Library, should be made available for loan or photocopying and be available via the Institutional Repository, subject to such conditions as the Librarian may require
5. I understand that as a student of the University I am required to abide by the Regulations of the University and to conform to its discipline.
6. I confirm that the thesis has been verified against plagiarism via an approved plagiarism detection application e.g. Turnitin.

ONLY for submissions including published works

Please note you are only required to complete the Inclusion of Published Works Form (page 2) if your thesis contains published works)

7. Where the thesis contains published outputs under Regulation 6 (9.1.2) or Regulation 43 (9) these are accompanied by a critical review which accurately describes my contribution to the research and, for multi-author outputs, a signed declaration indicating the contribution of each author (complete)
8. Inclusion of published outputs under Regulation 6 (9.1.2) or Regulation 43 (9) shall not constitute plagiarism.

* *Please note that it is the responsibility of the candidate to ensure that the correct version of the thesis is submitted.*

Signature of Candidate*:*	Anna Young Hunter	Date:	29/5/2020

Submission

Submitted By *(name in capitals):*	ANNA YOUNG HUNTER
Signature of Individual Submitting:	Anna Young Hunter
Date Submitted:	29/5/2020

For Completion in the Student Service Centre (SSC)

Limited Access	Requested	Yes		No		Approved	Yes		No
E-thesis Submitted (mandatory for final theses)									
Received in the SSC by *(name in capitals):*						Date:			

TABLE OF CONTENTS

List OF TABLES

Chapter 3

LIST OF FIGURES

Chapter 3

GLOSSARY OF ABBREVIATIONS

- YYIR1 – Yoyo intermittent recovery test

  A commonly used test for assessing aerobic capacity in team sports players.
- EF – Executive function/s

  Found in the frontal lobe it is responsible for the planning and reasoning.
- IGT – Iowa gambling task

  Card based gambling game which is a way of assessing executive function.
- PHV – Peak Height Velocity

  Commonly used biological marker that measures maturity.
- VO_{2max} – Maximal oxygen uptake

  Maximum amount of oxygen a person can utilise during maximal exercise.
- Km – Kilometres

  A measure of distance.
- TID – Talent Identification

  The identification of a highly skilled player at a young age.
- WCST – Wiscon card sorting test

  Card based game which assess executive function.
- CP – Cognitive processes

  The understanding and collection of knowledge via a mental action.

CHAPTER 1 – INTRODUCTION

High intensity running is a movement characteristic common across a range of invasion sports (characterised by teams trying to invade their opponent's half to create scoring opportunities), including Rugby Union (Cahill, Lamb, Worsfold, Headey, & Murray, 2013), Association Football (Castagna, Impellizzeri, Cecchini, Rampinini, & Alvarez, 2009) and Hockey (Jennings, Cormack, Coutts, & Aughey, 2012) among youth populations (Young, Dawson, & Henry, 2015). Recent research has investigated the relationship between high intensity running in, for example, match play, to physical characteristics such as total distance in the YoYo intermittent running test (YYIR1) (Bangsbo, Iaia, & Krustrup, 2008), sub-maximal aerobic capacity (Hulin, Gabbett, Kearney, & Corvo, 2015) and repeated sprint ability (Castagna et al., 2008). What is less developed, however, is our understanding of how higher order cognitive processes such as executive functions (EF) contribute to the ability to apportion effort during high intensity running tasks when work to rest ratios are not standardised or predetermined, as has been the case in traditional tests of physical capacity (Spencer, Bishop, Dawson, & Goodman, 2005) and training programmes (Ingebrigtsen, Shalfawi, Tønnessen, Krustrup, & Holtermann, 2013). Indeed, a recent paper highlighted the need to investigate not just the "size of the engine but also the ability of the driver behind the wheel to more effectively assess the high intensity running ability of team sport athletes" (Gibson & McCunn, 2019; pp1). To date, no research has been conducted into EF and the ability to pace high intensity running actions in youth team sport athletes. This will be the focus of this thesis.

Indeed, there is evidence that youth team sport players are less able to pace effort during high intensity exercise when compared to their adult peers (Brownstein, Ball, Micklewright, & Gibson, 2018; Gibson, Brownstein, Ball, & Twist, 2017). Whilst the ability to effectively apportion effort and recovery appears to improve as players become more biologically mature (Micklewright et al., 2012), our understanding of the processes which govern this are not well established. It has been suggested that the development of cognitive processes influence the ability of young people to pace effort during a continuous exercise task (Micklewright et al., 2012), however the relevance of such exercise to team sports that are intermittent in nature is questionable. Furthermore, no studies have as yet investigated the role of EF in pacing during intermittent running in youth team sport athletes.

It is established that cognitive functions play an important role in successful sporting performance, but the exact mechanism or mechanisms that contribute to this success are unclear (Cona et al., 2015). Vestberg et al. (2012) suggested a link between EF and sporting ability. EFs are linked with activity in the prefrontal cortex and are responsible for goal directed behaviour, including language and motor functions (Anderson, 2002). Recently EF has been equated to 'game intelligence' in soccer (Vestberg et al., 2012) referring to excellent spatial attention, divided attention, working memory and mental capacity.

'Game intelligence' is very important to players' performances. During high intensity intermittent exercise such as actual match-play, for example, players are required to identify and direct their attention to relevant cues i.e. opposition and own team positioning while also having the ability to look ahead to make sure they have enough 'fuel in the tank' to last the duration of an event. Suggesting EF could have a highly influential role to play in the ability of young players to plan ahead of a high intensity intermittent event and distribute energy accordingly.

1.1 - Defining Executive Functioning and its Trajectory

EF can be defined as a person's ability to problem solve to achieve a positive outcome. EF is a multifaceted construct, made up of many components. These components or behaviours impact/control a person's ability to problem solve. These include planning, inhibition of prepotent responses and impulse control (Ozonoff, Pennington & Rogers, 1991). EF is said to contain four elements (initiation, sustaining, shifting and inhibition), which provide the basis for higher order cognitive functions such as planning and reasoning (Diamond, 2013). EF acts as the 'brain's conductor', with one of its main roles being to adapt to unpredictable situations, which require rapid and dynamic changes of behaviour to fit the environmental demands, such as those seen in team sports (Burgess et al., 2006; Huizinga, Dolan, & van der Molen, 2006).

EF is also a neuropsychological construct which develops with age, emerging from birth and continuing its development until early adulthood (Anderson, 2002; Best & Miller, 2010). As cognitive functions mature the degree to which feedback is provided to youth populations influences the learning of new motor skills. During the earlier stages of development (childhood through to adolescence) augmented feedback (external source of advice/feedback provided by coaches or teachers) is useful for increasing learning and error detection when learning a new skill (Magill, 1994). Adams (1971) proposed that when learning a new skill, a learner must have knowledge of results. Knowledge of results can be interchanged with augmented feedback (Magill, 1994). From the prospect of learning a new skill or the development of a skill, a form of external feedback aids performance. With this being said, it is proposed that as cognitive skills improve during early adulthood, the need for external feedback decreases. Therefore, skills such as pacing are more greatly affected by external feedback with younger population.

1.2 - Executive Functioning and High Intensity Intermittent Exercise

During a single sustained period of high speed running a player must be able to control physiological and psychological (pacing) variables in order to produce an effective performance. In the past the focus has been on physiological variables having the largest influence on high speed running performance i.e. aerobic capacity and improved recovery after sprinting (Castagna, Manzi, Impellizzeri, Weston, & Barbero Alvarez, 2010; Meckel, Machnai, & Eliakim, 2009). This, however, does not explain why some players are better at pacing effort throughout an exercise task, such as match-play than others. Evidently, a factor beyond physiology itself must play a role i.e. Psychological factors.

High speed running or high intensity intermittent exercise requires players to look at the bigger game picture or final performance. A key question, therefore, is how long can they keep up the same intensity over the course of the exercise? During match play for example, players have to use periods of constant speed running alongside periods of acceleration and deacceleration to cover a set distance in a specific timeframe. The capacity to know when to "take their foot off the gas" and when to go "hell for leather" is important. This is where a player's pacing ability comes into play. The ability to pace is a highly influential factor in successful high intensity exercise performance.

1.2.1 - Pacing

Pacing is described as the ability to anticipate the demands of an exercise task and the ability to adjust pace during said task to meet its changing demands in order to avoid suffering premature fatigue. This capacity to change pace during exercise is regulated by continual afferent and efferent feedback, which aims to ensure the endpoint is attained (Chinnasamy, St Clair Gibson, & Micklewright, 2013). This ability to pace effectively during match-play requires a player to assess the game intensity, score line, opposition, their position and time remaining in order to adjust performance to fit needs of a game. These skills require the use of cognitive abilities such as planning, anticipation and working memory; which are all components of EF.

1.2.2 - EF and high-speed running

To date, the influence of EF on such things as high intensity interval running has not been investigated. In the past, studies have taken more of a general approach, by looking at match-play as a whole for example, rather than splitting it into different entities such as pacing or technical skills when assessing EF and sports performance. Vestberg et al. (2012) found a positive relationship in adults between scores in a test of EF (design fluency test) and the number of goals and assists achieved during a soccer season. Furthermore, Mann et al. (2007) found higher level players produced significantly greater EF scores compared to their lower division counterparts in team sports. Until now, no study has taken a deeper look at how EF may affect different components of a player's game, such as their ability to pace during high intensity intermittent exercise.

It has already been said that EF is a multifaced construct containing many different components. One of these components, for example, is planning. During high intensity intermittent exercise (brief all-out effort followed by low intensity exercise or rest), a player must plan ahead in order to know how and when is the best time to expend energy. This planning ability is controlled/managed by EF; therefore, a potential link can be seen between EF and how a person plans and distributes energy during a high speed or high intensity intermittent running task.

1.3 - Development of Executive Functioning and Pacing in Youth players

A player's pacing ability has been suggested to develop throughout childhood into adolescence (Micklewright et al., 2012). Previously focus has been more on physical characteristics as a player grows rather than psychological attributes. This is due to things such as aerobic capacity increasing in adolescence, which influences pacing performance (Castagna et al., 2010).

However, as a young person develops, cognitive elements improve too. Recently, a link has been found between a youth player's intellectual development and their ability to pace. Micklewright et al. (2012) found a player's pacing ability increased with their stage of cognitive development. According to (Piaget, 1974) there are four stages of cognitive development: sensorimotor (0-3 years), pre-operational (4-7 years), concrete operational (8-12 years) and formal intelligence (13-18 years). Using Piaget theory, Micklewright et al. (2012) found participants were better able to pace when the formal operational stage was reached. This improvement in pacing was demonstrated as participants were able to utilise an end spurt and demonstrate an inverted U pacing strategy. This is the stage at which a person can “engage in hypothetical and deductive reasoning” (Chinnasamy et al., 2013). This follows a similar development trajectory as EF, with a ceiling effect reached around 18-20 years old (Anderson, 2002). Research shows as a person matures their level of EF increases (Anderson, 2002; Anderson, Jacobs, & Anderson, 2008; Anderson, Anderson, Northam, Jacobs, & Catroppa, 2001). Creating a potential link between a youth player’s EF and their pacing capabilities.

1.4 - Measuring Executive Functions

Limited research has studied EF in a sporting capacity as it is a difficult entity to measure. Which cognitive tests are most applicable or useful has not been established. Verburgh et al. (2014) argued the design fluency test which was used in Vestberg’s et al. (2012) study does not give an accurate indication of EF abilities. The design fluency test requires players to join dots in a square with one line using a pen. It measures creativity, cognitive flexibility and inhibition (Vestberg et al., 2012). The study found experts (footballers) to possess higher levels of EF when testing the following components: motor inhibition, working memory and attention. Experts were able to supress ongoing motor responses and attain an alert state better than novices.

An athlete’s cognitive skills have been linked to their reaction time in executive control and visuospatial attention tasks (Alves et al., 2013). Alves et al. (2013) found experts task switching and stopping ability to be greater than novices in a sample of volleyball players. The comparison of expert and novices demonstrates that experts have a greater ability to identify new information and integrate it with existing knowledge to produce an appropriate response (Mann et al., 2007; Voss, Kramer, Basak, Prakash, & Roberts, 2010). Mann et al. (2007) suggested this difference was attributed to experts having a greater capacity to recognise important and relevant information from the surrounding environment.

Although there is an established association between cognition and performance (in the tasks utilised), there are limitations. For example, most studies investigating cognitive skills used sport specific tasks such as pattern recognition, knowledge of situational probabilities and decision-making (Mann et al., 2007). There is debate as to whether expertise in sport specific cognitive tasks translates to all sporting contexts and whether this expertise has a link to EF abilities (Vestberg et al., 2012). EF is a higher order process but cognitive tests such as the above do not tap into all the domains of EF. Only a few studies have actually investigated EF (rather than general cognitive abilities) and sports performance.

Past research has failed to grasp where, when and how EF might impact sporting performance, with research focusing on sporting performance as a whole rather than splitting it into separate entities. For example, Vestberg et al. (2012) research showed improved EF increased goals and assists during a soccer season but the question is how did it improve these variables? The ability to score goals or create assists is dependent on many things such as who a player passes to, whether they shoot rather than passing, making the right run or getting into the right position. The latter two relate to a player's pacing ability. A player must weigh up the cost of expelling energy and the likelihood of scoring or creating a chance. It is hard to draw conclusions on EF and sporting success if a game is measured as a whole entity. Therefore, looking at specifics within match-play, such as the impact of EF on pacing ability, will give a better indication of why a player may choose to make that run to the back post or hold back, which in turn impacts variables such as goals scored or assists achieved as seen in Vestberg et al. (2012) study.

Furthermore, it has been shown that youth populations struggle to allocate appropriate recovery periods during repeated high intensity bouts (repeated high intensity bouts are a movement characteristic of team sports) (Brownstein et al., 2018; Gibson et al., 2017). It is suggested that cognitive development is the main determinant of the inability of youth populations to proportion effort during repeated high intensity bouts. Therefore, proposing that the stage of EF an athlete is at is important in their ability to pace effectively during match-play.

1.5 - Justification for Research

The lack of literature regarding EF and a young player's ability to pace during high intensity intermittent exercise (which is relevant to team sports) provides scope for future research. The existing literature does not go into detail regarding the development trajectory (path of improvement) of higher order cognitive processes such as EF and how this may affect a team player's ability to pace during high intensity intermittent exercise that is not governed by external cues. There is little reference to how coaches may utilise information gained about a player's EF ability in their training and development which can have a detrimental effect on a young player's progress to the professional game.

In addition to this, there is a lack of research looking into the possible influence feedback, particularly external feedback, may have on EF and a player's ability to pace during prolonged high intensity intermittent exercise. In a normal training environment, the amount of external feedback from coaches, players or other staff is high. This is not representative of competitive situations such as match-play. During which coaches have less opportunities to provide players with feedback, meaning players must make independent decisions. It is therefore prudent to investigate whether young players pacing performance is affected by how much and when they receive feedback during a high intensity task.

Here I explored the relationship between EF and a young player's ability to self-pace during a bout of high intensity intermittent exercise with reference to how external feedback and maturity may influence this ability to pace.

I hypothesised that young people who demonstrate superior EF will have greater pacing skills. Pacing strategy is expected to be more efficient with the addition of external feedback.

CHAPTER 2 – LITERATURE REVIEW

2.1 - Pacing in Team Sports, why is it Important?

Pacing and distribution of energy resources is an influencing factor for a successful athletic performance (Abbiss & Laursen, 2008). In team sports for example, players are required to continually make decisions regarding how and when they should invest energy to achieve optimal performance (Smits, Pepping, & Hettinga, 2014).
The term pacing refers to the ability to distribute work effectively and/or the ability to choose an optimal pattern of energy expenditure during exercise (Abbiss & Laursen, 2008). Pacing aims to help regulate exercise intensity during physical activity in an attempt to maintain homeostasis and avoid early fatigue (Smits et al., 2014) with decision-making referred to as the ability to choose an suitable action from an array of possibilities to achieve a specified end goal. (Smits et al., 2014). A successful pacing performance is dependent on both biomechanical and metabolic demands of a given task in order to regulate performance (Ulmer, 1986).

Invasion games, such as team sports, vary in length, intensity and stoppage periods. The nature, duration and intensity of the game will dictate how players pace. Players must be able to make decisions about pacing throughout a game to aid energy conservation and avoid premature fatigue. Fatigue is one of the over-riding factors that dictates a player's ability to make decisions during a high intensity task such as a football game (McMorris & Graydon, 1996) and is thus a key component for decision-making and pacing (Smits et al., 2014)

Evidence has shown that the pacing strategy a player adopts is often circumstantial to many factors such as: demands of the task, personal goals, previous experience, knowledge of end-point and environment (Billaut, Bishop, Schaerz, & Noakes, 2011; Duffield, Coutts, & Quinn, 2009; Tucker, 2009b)

2.1.1 - Role of Cognition

One area of the literature that has not been fully explored is how cognitive skills may affect pacing ability and the mechanisms that regulate these skills. Recently, it has been argued that the regulation of physical effort is dispersed between the subconscious and conscious brain (Edwards & Polman, 2013). To avoid excessive or early fatigue the brain sends afferent/efferent signals to ensure completion of the task (Edwards & Polman, 2013). Afferent signals refer to physiological signals, such as cardiorespiratory sensations, temperature and blood/muscle pH, which influence an athlete's perception of effort during exercise (Edwards, Bentley, Mann, & Seaholme, 2011). These afferent signals cause adjustments in efferent control via a feedforward process, which affects motor unit recruitment i.e. alters the rate, type and frequency (Thompson et al, 2014).

This feedforward process controls the regulation of effort during physical activity as it changes the perception of the demands of a given task (Micklewright et al., 2012; Tucker et al., 2008). Unlike feedback control, the feedforward process is not regulated by close loop control, so, the feedforward process allows the production of an action in advance allowing a reduction in disturbances to the system better than feedback control can alone (Basso & Belardinelli, 2006). The feedforward process is made up of both sensory-perceptual and cognitive elements. It is the cognitive component which controls the decision-making process involved in the adoption of a pacing strategy for exercise with a known end-point (Albertus et al., 2005; Ansley, Robson, Gibson, & Noakes, 2004).

A variety of cognitive skills are involved in the selection of pacing strategies, these include planning, reasoning and anticipation (Micklewright et al., 2012). These skills are all involved in the decision-making process. The ability to interrupt and adjust pacing strategy via internal feedback such as perceived exertion is influenced by cognition (Eston, 2009). A player must be-able to read and respond to both physiological and psychological cues to produce an effective pacing strategy.

These skills involved in pacing are also part of the overriding controls of goal-directed decision-making, which are also the same/similar to those skills that describe EF abilities. Currently, it is proposed EFs are the ‘control centre’ for higher order cognitive skills such as planning and inhibition (Best & Miller, 2010; Diamond, 2013). With this is mind, EF could potentially give a picture of an athlete’s ability to pace. The process of testing EF requires athletes to anticipate what is going to happen and form a strategy, which is very similar to the process involved in pacing during high intensity running with a specific aim yet no external cue to govern behaviour.

2.1.2 - Youth Athletes and Pacing

The youth athlete population refers to those athletes going through puberty or who have not reached adulthood. Pacing as with most things improves as an athlete goes through the development process. Micklewright et al. (2012) found that pacing ability was highly dependent on the stage at which a young person is at in their intellectual development. Intellectual development is said to contain four stages: sensorimotor (0-3 years), pre-operational (4-7 years), concrete operational (8-12 years) and formal intelligence (13-18 years) (Piaget, 1974). As a young person progresses through these stages their cognitive ability increases from a point where during the sensorimotor stage they are unable to anticipate the demands of a task and conserve energy until the formal intelligence period in which they can internally represent and anticipate the demands of a task (Micklewright et al., 2012; Piaget, 1974). Therefore, pacing strategies adopted to avoid premature fatigue are dependent on intellectual competencies with initial and ongoing pacing adjustments heavily influenced by an individual's decision-making ability (Micklewright et al., 2012). As an athlete progresses through these stages, there cognitive skills improve and hence develop increased pacing capabilities. It is during the formal intelligence period of development where abstract reasoning and propositional logic are used in the problem-solving process (Piaget, 1974). These skills are not fully developed until adolescence (Luna & Sweeney, 2001), suggesting an individual's pacing ability develops with age.

It is not a coincidence that pacing ability increases with cognitive development. During intellectual development, EF increases reaching a ceiling around 18-20 years (Anderson, 2002; Anderson et al., 2008; Anderson et al., 2001). It is at this age that formal intelligence is reached, which is in line with Micklewright et al. (2012) findings, suggesting that EF has an important role to play in pacing abilities of youth athletes.

2.1.3 - Previous Pacing Research

Traditionally the literature provides evidence to support the role of physiological variables in pacing performance. Baron et al. (2009) studied participants performing a variety of fatiguing tests i.e. 400m run, 60m sprints (uphill and downhill) with running speed significantly lower during the uphill running tests. During the downhill phase greater eccentric contractions occurred, thus suggesting pacing strategy was influenced by the mechanoreceptors which are more active during downhill running Baron concluded that the level of eccentric muscle loading impacts pacing strategy. Furthermore, studies have claimed glycogen level in the muscle's influences pacing as it has afferent signalling components. Lowering of glycogen levels in the muscles acts as one of the signals for fatigue (Lambert, St Clair Gibson, & Noakes, 2005; Timothy David Noakes, 2012). Rauch and colleagues' (2005) study on cyclists performing a one-hour time-trial at 73% VO_{2max} (Maximal oxygen uptake attained during maximal exercise intensity) (Hill & Lupton, 1923) found when participants were carbohydrate loaded their workload was greater after the first minute than in the non-carbohydrate loaded condition, implying pacing strategy was adapted in the non-carbohydrate loaded condition.

Furthermore, pacing literature has focused on endurance sports such as marathon running and endurance cycling. In these events, pacing strategy usually follows the fast-starting strategy with starting speed greater than the average speed for the race (Lima-Silva et al., 2010). An athlete's speed gradual declines until 90% of the race is complete, at which point an increase in speed is seen, known as the "end spurt" (Joseph et al., 2008; A. St Clair Gibson, Schabort, & Noakes, 2001). This results in a U or J-shaped pacing strategy (Abbiss & Laursen, 2008). However, some athletes adopt positive and negative pacing strategies during a race/exercise task. Positive being when an athletes reaches 'peak speed' and then slows; while negative is starting slow and then speeding up as the event progresses (Abbiss & Laursen, 2008).

Positive and negative splits may be the result of an athlete's anticipation of the demands of a task, which has found to greatly influence pacing strategy (Billaut et al., 2011; Tucker, 2009a). For example, Tucker et al. (2004) study on trained cyclists in the heat found a reduction of power output as a likely result of anticipation to avoid hyperthermia. However, the study also reported an increase in power output in the last 5% of the 20km time trial, even when body temperature was at its greatest.

Studies investigating cyclists pacing strategy show that knowledge of distance can also be an influencing factor on performance (Albertus et al., 2005; Nikolopoulos, Arkinstall, & Hawley, 2001), with Nikolopoulos et al. (2001) finding power output and heart-rate did not change when cyclists completed two different distance time-trails, when actual distance was not given.

Additionally, pacing studies on continuous activities have proved the influence of fatigue, emotions and perceived exertion to play a key part in which pacing strategy an athlete adopts (Albertus et al., 2005; Baron, Moullan, Deruelle, & Noakes, 2011; Hettinga et al., 2011).

Even though there is a wealth of knowledge of pacing in continuous activity, there is limited research around pacing in intermittent exercise, for example in team sports like Association Football. Intermittent exercise could potentially be more demanding than continuous sports on pacing capabilities due to the different speeds, duration and length of running in team sports. Intermittent sports such as team sports provide a complex performance environment, that requires athletes to continually evaluate and modify behaviour to fit this everchanging environment (Smits et al., 2014). The demand intermittent sports present compared to continual sports is greater as athletes must make decisions related to exteroceptive (environmental) influences alongside internal factors (Smits et al., 2014).

In team sports, athletes must be-able to regulate both exercise intensity while allowing adequate recovery to sustain the intensity required to complete the game or task successfully. To be able to do this an athlete must be-able to continually assess the task to plan ahead and have the ability to adjust plans dependant on changes during the game or task.

It would therefore be beneficial to determine how pacing strategies may differ in intermittent sports in comparison to continuous sports. The evidence seems to suggest that pacing strategies in intermittent sports may be highly dependent on an athlete's cognitive skills and their ability to adapt to the environmental changes (Micklewright et al., 2012; Smits et al., 2014).

Recent research has shown that youth populations differ to adult populations when self-selected recovery is employed during high intensity intermittent exercise. With adults found to take longer recovery periods when using self-selected recovery between high intensity bouts than youth populations (Phillips, 2014). It has been found that when self-selected recovery is used during high intensity intermittent exercise, recovery time selected by athletes is significantly greater, with an enhanced ability to maintain or reach a target speed than when recovery is governed by an external source (McEwan, Arthur, Phillips, Gibson, & Easton, 2018). Gibson (2017) found youth footballers (13.7 ± 1.1 years) found it harder to maintain an effective sprint performance via the manipulation of recovery duration. With youth populations taking shorter recovery periods between high intensity bouts such as sprinting than when used in adult populations. It is thought this is a result of youth populations finding it more difficult to interpret the surrounding environment and task in order to select appropriate rest periods. As previously mentioned, it is believed that this could be a result of the stage of cognitive development an athlete is at (Micklewright et al., 2012). It is proposed that until children reach the 'formal intelligence' phase of cognitive development they struggle to conceptualise a high intensity intermittent exercise task requirements (N. Gibson et al., 2017; Micklewright et al., 2012).

2.2 – Can Talent Identification Predict Pacing Ability?

Throughout the duration of a young athlete's development, tests are continually carried out to compare their abilities with others. This is known as talent development (TD). TD is the process of recognising players who have the potential to excel in each sport (Roel Vaeyens, Lenoir, Williams, & Philippaerts, 2008). The vast majority of this testing is done in the adolescent years (13 – 19 years) (Pearson, Naughton, & Torode, 2006). Every academy (programme or facility set-up to develop young players/athletes) or development programme in team sports will have a structured TD procedure or 'testing battery'. Clubs enrol promising players from an early age, with the aim to provide them with specialised programmes to enhance their playing ability (Vaeyens et al., 2006). It is therefore very important for clubs to have a TD programme that is effective.

2.2.1 - Current Talent Identification Development Procedures

Predictors of future success in team sports include: physiological, psychological, neuromotor (motor unit recruitment) and anthropometric (height, weight) variables (Vaeyens et al., 2008; Vaeyens et al., 2006). Within TID (talent identification development) programmes physiological and anthropometric variables tend to be the focus (Vaeyens et al., 2008; Vandendriessche et al., 2012). Physiological measures include: strength, flexibility, speed, aerobic endurance, anaerobic capacity (Vaeyens et al., 2006). With many clubs using Mirwald et al. (2002) maturity offset equation: Peak height velocity (PHV) equation as a predictor of biological maturity.

Physiological tests often include sprinting or high-speed running, such as the yoyo intermittent recovery test. Currently, when testing, standardised recovery is employed i.e. 10 seconds between runs (YYIRI test). When used across a wide spread of age groups i.e. children (13 years and below) to adolescents (13 – 19 years), the data produced may not be representative of that population due to the varying stages of physiological and cognitive development. It is well established that fatigue susceptibility differs in children and adults with onset of fatigue much slower and recovery quicker in children during high intensity exercise (Brownstein et al., 2018).

Recent research has suggested that young athletes may not have the capacity to allocate appropriate recovery times during a repeated sprint task (Brownstein et al., 2018). Due to athletes always having been given set recovery times, they never have to strategize or assess their fatigue or energy levels. This is a vital skill in a game. Therefore, self-selected recovery may be useful to implement in testing procedures.

2.2.2 - Impact of Psychological Characteristics

Current TID programmes focus on a limited range of variables, with changes in performance accounted for via a small pool of characteristics (Vaeyens et al., 2008; Vandendriessche et al., 2012). Physiological variables such as, aerobic power, muscular strength and muscular endurance are only one piece of the puzzle in early talent detection in sport (Lidor, Côté, & Hackfort, 2009; Vaeyens et al., 2006). Excellence in sport is not only a product of physiological attributes but also psychological. Testing psychological traits could be effective for coaches as it may help them understand things such as what will motivate an athlete, how an athlete may cope with stressful or competitive situations and their decision-making ability (Abbott & Collins, 2004; Lidor et al., 2009).

Evidence points towards psychological attributes being the difference between elite and non-elite in a sporting environment (Mann et al., 2007). Greater cognitive-perceptual skills have been shown to be the difference between elite and non-elite athletes (Mann et al., 2007; Voss et al., 2010). The difference between elite and non-elite was not apparent when athletes were tested on physiological measures alone (Vaeyens et al., 2006). Vaeyens et al. (2006) found elite athletes showed greater speed and strength scores than non-elite athletes however, there was no difference when it came to technical skills i.e. passing and shooting in youth football players. Overall, elite athletes produced a better performance than non-elite, thus suggesting there were other factors that impacted performance, such as cognition.

With a difference in technical skills not apparent it may be an increased cognitive skill set that separates two groups of athletes. Elite athletes have a greater ability to depict and interpret information provided to them, than novices (Williams, 2000), with experts shown to have a quicker response time and processing speed (Voss et al., 2010) alongside the ability to employ fewer fixations on an object or environment during quiet eye to extrapolate the most important information needed in the decision-making process (Mann et al., 2007).

Tests which assess a player's abilities to interrupt the environment, anticipate plays, plan responses and to make decisions fast would be very useful to coaches (Lidor et al., 2009). Therefore, it may be prudent for TID programmes to measure not only physiological variables but psychological variables too.

2.2.3 - Psychological Tests and TID

As mentioned above there is a lack of psychological tests used within modern TID framework. There are multiple ways in which an athletes psychological or mental skill can be tested.

Sporting environments create stressors for athletes which effect their momentary mental capacity. Tests can be given to indicate an athlete's mental capacity and how they might react and perform under certain stressors, for example, the SCAT test (sport competition anxiety test) (Martens, 1977). The SCAT test, assesses an athletes competitive trait anxiety via a questionnaire.

Cognitive-perceptual skills such as vision, anticipation, memory recall and response time have often been tested in athletes (Ward & Williams, 2003). For example: Specific game play sequences are used to test anticipation. This allows assessment of a player's ability to look ahead or their knowledge of what happens next based on information, such as postural cues (Ward & Williams, 2003). For example, a defender will watch an opposition attackers body position to determine where/what they will do next in order to choose the ideal moment to put in a tackle or interception.

Recently, literature has suggested EF may be a good psychological measure for not just TID but for athletes in general. A few studies have suggested that EF may be a useful predictor of future performance (Verburgh et al., 2014; Vestberg et al., 2012). To do this players performance was tested in non-sport specific cognitive tests (design fluency test) and compared to certain performance outcomes during a soccer season.

This past research implies that cognitive factors could be highly influential on team sports performance and therefore would be a useful tool during the TID process and beyond. As of yet there is no concrete evidence on what these cognitive skills are. During team sports athletes make decisions constantly and it is these decisions that impact the outcome of a game. Psychological skills should be considered alongside physical ones during the TID process.

2.3 - Understanding Executive Functions

EF is regarded as a subcategory of cognitive functioning. EF is present in situations that require planning, problem solving, inhibition and vigilance (Diamond, 2006). Acting as

a control mechanism EF regulates cognition via a set of sub-processes (Miyake et al., 2000). The primary purpose of these sub-processes is to adapt to unpredictable environments the likes of which are seen in team sports (Burgess et al., 2006; Huizinga et al., 2006). EF's are used in both goal-oriented action under distraction and novel responses when well-learned responses are present (Unsworth et al., 2009).
EFs were first proposed by Baddeley & Hitch (1974) via their model of working memory. They concluded that working memory was made up of two sub-systems: the articulatory loop and the visuo-spatial scratch-pad, which feed into the 'central executive'. The central executive is the core of the system which controls and coordinates information from the two subsidiary slave systems (Baddeley, 1983). The central executive is assumed to act like a finite attentional system that selects, or de-selects control processes and strategies involved in the decision-making process (Baddeley, 1983).

Good decision-making ability is very important within team sports. It is present in all sporting actions such as choosing the correct pass or setting up in the correct position off the ball. It is proposed that EF is what controls these decisions.

2.3.1 - Evaluating Executive Functions

EF is a multifaceted construct that means it does not have a standardised measure (Best & Miller, 2010). It is very difficult to create or design a test which taps into all components of the EF construct. With this said previous research has used a variety of different tests which aim to tap into one of more components of EF.

Some of the most commonly used tests to assess EF are the Wisconsin card sorting test (WCST), the tower of Hanoi and the Iowa Gambling test. These tests assess planning ability. The tower of Hanoi for example, uses three pegs and three disks of different sizes. The disks all start on peg one and the aim is to move all the pegs to peg three, one disk at a time (Anderson, 2011).

The issue with EF tests is they are not domain specific. When testing EF in a sporting environment, conjecture exists around how you determine a true translation of decision-making ability in a competition environment; whether EF should be tested using sport specific or non-sport specific tasks remains unanswered?

Past research has conflicting views on whether testing EF should involve a sport specific or non-sport specific task. Some studies argue that in order for a true reflection of EF ability to be demonstrated it must be representative of the activity (Mann et al., 2007; Vestberg et al., 2012). In contrast, Vestberg et al. (2012) argues that trying to implement sport specific EF tasks does not give a true reflection of EF ability as it does not look at EF as a whole. By assessing EF outside of a competition environment in theory should still give a good indication to how a player might perform on the pitch.

Cognitive skills transfer is a term used when explaining how training cognition via one type of task or activity may increase performance in another untrained cognitive tasks (Jacobson & Matthaeus, 2014). Every task consists of various different skills and knowledge with any tasks that share the same types of skills and knowledge having a strong transfer effect (Taatgen, 2013). For example, testing a player's planning ability via tasks such as the WCST, should in theory give an indication to how well a player can plan in a playing environment, which is highly important in team sports? During a team sports game there is limited opportunity for a coach to give instruction to a player once the match has started. The planning ability of EF may allow athletes to think on their feet during a game and change their plan according to what is unfolding around them.

2.3.2 - Influence of Maturation on Cognition

From childhood through to adulthood the brain undergoes significant maturational changes which enable more sophisticated thoughts and actions (Supekar, Menon, & Sporns, 2012). Basic Cognitive processes such as working memory are seen in early childhood, but the more complex higher order cognitive processes continue developing throughout adulthood (Diamond & Goldman-Rakic, 1989; Supekar et al., 2012). Skills which develop over a protracted period are the abilities to plan and problem solve. Problem solving relies on the maturation of processes that control attention and resource allocation (Luna & Sweeney, 2001; Supekar et al., 2012).

One of the underlying reasons for this ongoing development is the continuing development of the pre-frontal cortex alongside increases in linkages between various brain regions (Steinberg, 2005). These changes increase communication and connectivity of the different regions of the brain particularly in the frontal lobe which is crucial for EFs (Steinberg, 2005). It is thought lower level cognitive processes such as processing capacity and information storage need to be fully developed first alongside the ability to inhibit responses for higher order cognitive processes to fully mature (Case, 1992; Luna & Sweeney, 2001).

2.3.3 - Executive Functions and Maturation

As with other Cognitive processes (CP), EF has its own development timetable. EF being a multi-componential construct means each of the various components emerge and mature at different rates throughout childhood into adolescence (Anderson, 2002; Best & Miller, 2010). EF falls into the category of higher order cognitive processes, which means it matures later than some of its lower order cognitive counterparts. Simple information processing is said to be fully developed by 12 years of age, whereas working memory and inhibition do not reach full maturity until around 15 years of age (Verburgh et al., 2014). As you progress further into adolescence the ability and competence of every individual EF ability improves (Best & Miller, 2010). This increased competence is associated with the further maturity of the prefrontal cortex, which is key to the EF construct (Best & Miller, 2010).

EF relies on the integrity of the frontal lobe systems, the development of which extends into adulthood (Anderson, 2002). Research has suggested that as a task becomes more complex the degree to which frontal lobe resources are used increases (Jacobs, Harvey, & Anderson, 2011). Imaging studies have reported increased activation of the frontal lobe when adults are given EF tasks such as the Stroop test (Collette, Hogge, Salmon, & Van der Linden, 2006).

Full maturity of the brain is vital for full evolution of EF (Tamm, Menon, & Reiss, 2002). Tamm et al. (2002) reported younger children showed increased activation in the frontal lobe regions when using a Go/No Go paradigm (test which requires a participant to produce a simple motor response to one cue while inhibiting the response of another cue), than was seen in adults (Trommer, Hoeppner, Lorber, & Armstrong, 1988). This increased activation was suggested to be a result of children using less efficient strategies to complete the task that demonstrates less developed EF. Consequently, Wood and Rutterford (2004) suggested the activation of the frontal regions was directly linked with task efficacy, therefore the maturation of the brain appears vital for increased performance in EF tasks.

EF matures naturally as children develop. However, the process can be accelerated through coaching and learning. From a young age, children can improve specific components of EF such as working memory through simple cognitive tasks on a computer (Diamond & Lee, 2011). During an athlete's younger years, the development of EF could prove to be vital. It is during adolescence that children are selected into performance programmes. EF is said to reach a ceiling effect around 18-20 years of age (Anderson, 2002). This is the most important point in a player's career. At this point they need to not only have exceptional physical attributes and skills but also a fully developed set of cognitive skills. It is highly developed cognitive skills that set players apart from each other (Miyake et al., 2000).

2.4 - Measuring Pacing Performance

In the literature, pacing strategies have been measured predominantly during cycling or running performance. Originally pacing was assessed using continual endurance-based exercise. For example, a set distance time trial (Tucker et al, 2004). In recent years, there has been a greater focus on how pacing strategies differ in team sport or intermittent sports and how this differs from that of steady state endurance exercise. With many studies adopting a repeated sprint or high intensity running protocol (Gibson, Henning, & Twist, 2018; Glaister, Howatson, Pattison, & McInnes, 2008; McEwan et al., 2018; Phillips, 2014).

Most pacing studies to date have been conducted in a controlled environment i.e. a lab. The issue with this being, how applicable is it to sports such as football, Hockey, and Rugby. These sports are played over a prolonged period, with players required to run at differing distances and intensities. It would be more beneficial if athletes were assessed in an environment that was more reflective to match-play. Recently, pacing studies have tried to implement protocols which are more ecologically valid, this means the implementation of varying exercise intensities and recovery durations.

Exercise Intensity

Pacing strategy is highly dependent on exercise intensity and duration (Waldron, Highton, Daniels, & Twist, 2013). During a competition environment athlete are usually required to assess the intensity and duration of exercise. This will affect the pacing strategy used. Swain (1997) showed that during a 10km cycling time-trial, performance was greater during uphill sections of a race compared to cycling at a constant intensity.

End point

Studies in the past have tended to adopt a protocol which included a defined end point. It has already been concluded that end point greatly influences pacing strategy (Albertus et al., 2005; Baden, McLean, Tucker, Noakes, & St Clair Gibson, 2005). Tucker et al (2004) found during a 20km cycling time trial recreational athletes adopted more of a 'parabolic' strategy. With speed dropping off after an initially faster start and then increasing again during the last 5% of the trial. In this instance knowledge of ‘end point’ influenced the pacing strategy adopted.

When considering a youth population, the way in which ‘end point’ is given affects pacing performance. Chinnasamy et al. (2013) found that young athletes running performance changed dependant on whether spatial or temporal cues were given. Youngest athletes were found to perform better when a running task ‘end point’ was defined by distance rather than time (Chinnasamy et al., 2013). Which could suggest youth athletes do not have the cognitive capacity to interpret efferent signals to respond appropriately to spatial cues but instead need an end point they can actually see i.e. distance.

Less literature surrounds pacing in team sports where movement demands are not wholly dictated by distance or time but by position, game intensity or score-line. For a true translation, pacing strategy needs to be assessed in a competition environment where an athlete’s pacing is influenced by the above factors.

Recovery length

Frequently, when assessing an athlete, standardised recovery periods are employed whether this be in tests such as the yoyo intermittent recovery test or repeated sprint performance. Data has suggested that this approach is not representative of competitive match play, with sprint protocols for example, using an increased number of sprints and recovery duration than seen in matches (Buchheit, Mendez-villanueva & Simpson, 2010).

Recent data suggests that adopting self-selected recovery periods instead of a standardised recovery period may be a better way of assessing athletes that is more representative of match-play (Gibson et al., 2018). Glaister et al. (2010) found people were able to maintain sprint performance when self-selected recovery is implemented. Thus, suggesting an athlete is able to self-regulate work rate accurately without the use of external time-pieces (Glaister et al., 2010). Furthermore, Phillips et al (2014) also showed sprint cycling performance was not impaired when self-selected recovery was employed.

During a team sports game athlete must have the capacity to choose their own recovery periods based on feedback from physiological and cognitive parameters and the game demands. The above research indicates that athletes are able to maintain optimal performance when own recovery periods are selected as seen in match play situations.

This ability is not always apparent when athletes are younger therefore some developmental processes (cognitive) must have to take place before adulthood.

2.4.1 - Pacing Strategies and Matchplay

Pacing strategies adopted by athletes are dependent on a variety of variables, such as, but not limited to: distance, end point and environment (Billaut et al., 2011; Duffield et al., 2009). Defining an optimal pacing strategy is difficult due to the many variables that effect it. In individual sports adopting the correct pacing strategy usually enables an athlete to complete a known distance in the quickest time possible (Waldron & Highton, 2014). The most commonly used pacing strategies are ‘all out’ (Fast start, slower finish), ‘even paced’, ‘slow start’ (Start slow, faster finish) and ‘Parabolic’ (Fast start, slow middle of race and fast finish) (Abbiss & Laursen, 2008; Waldron & Highton, 2014).

Generally speaking, ‘all out’ approaches are usually adopted by those participating in short (<4min) time-trial performance, with middle to long distance races following a more ‘even paced’ approach (Waldron & Highton, 2014). Pacing profiles for team sports cannot be generalised in such a way, with pacing during match play highly dependent on the duration and structure of the sport i.e. rules and tactics. Additionally, environmental factors such as opposition and score can also influence how a player paces (Waldron & Highton, 2014).

Studies in football and rugby have found players running performance decreases towards the end of a match (Waldron et al., 2013). With football players total distance decreasing by 20% between the first and last 15 minutes of a match and a 20-30% drop in high intensity running distance in rugby players between the first and final quarter (Bradley & Noakes, 2013; Mohr, Krustrup, & Bangsbo, 2003; Sykes, Twist, Nicholas, & Lamb, 2011; Waldron et al., 2013). It seems team sports players tend to have two aims when adopting a pacing strategy for a match, it is important they last the whole game duration but also adopt a strategy which also allows them to incorporate shorter higher intensity bouts. This is done by using a macro and micro style pacing strategy (Waldron & Highton, 2014). It has been suggested a player will adopt a ‘slow-positive’ strategy, meaning their running intensity will slowly decrease over the period of a game (Waldron & Highton, 2014). This strategy permits a player to complete a match whilst also having enough energy for periods of higher intensity activity, this requires a micro-adjustment of pacing strategy (Waldron & Highton, 2014).

During match-play, the environment is so unpredictable it is hard to define an optimal pacing strategy with pacing highly-dependant on factors such as score-line, opposition and duration.

2.5 - Conclusion

The ability of an athlete to pace effectively is dependent on a number of physiological and psychological factors. This literature review argued psychological skills may a better way to measure or predict pacing ability. These psychological skills are influenced by cognition, understanding of the task and memory (Eston, 2009).
The cognitive skills which are used in or during pacing such as planning, inhibition and decision-making are all components of EF. What we know about EF and their importance may provide a good way in which to predict pacing abilities. The overlap of cognitive skills needed for pacing and those that make up EF, means it is prudent to suggest measures of EF may indicate an athlete's on pitch decision-making skills such as their ability to pace.

Research has already showed a link between EF and sporting success in all sports such as football, however there has been little focus on how EF may impact specific skills such as pacing and whether EF can be used to measure pacing ability.

Given the importance of cognitive skills in pacing performance, it may also be important to look at the influence of maturation on pacing ability. Cognitive skills have a development trajectory, with research showing more mature children having superior pacing capabilities (Micklewright et al., 2012).

CHAPTER 3 - STUDY

3.1 – Introduction

High intensity intermittent running performance is an important component of match-play during sports such as, invasion games. The amount and distribution of high-speed running during match-play is highly dependent on a number of factors, such as, duration, score line and opposition. A player must assess these factors to allow effective distribution of effort during the whole of a game to produce an efficient performance; this is known as pacing.

Pacing is defined as the ability to anticipate the demands of a task and distribute energy accordingly (Micklewright et al., 2012). Pacing strategy and distribution of energy resources is integral to athletic performance (Abbiss & Laursen, 2008). Exercise tasks vary in nature with different pacing strategies adopted dependant on event duration, intensity and structure (Abbiss & Laursen, 2008).

Recently studies have investigated how different pacing strategies are employed when using self-selected recovery during a high intensity intermittent running tasks (Brownstein et al., 2018; Gibson et al., 2017). Self-selected recovery protocols provide interesting insight into how an athlete or player may pace during exercise. Invasion games, for example are very stop start in nature and require a player to distribute energy throughout the full duration of a game. The current research shows younger invasion games players find it hard to apportion recovery in a way it doesn't detract from their performance during high intensity intermittent exercise tasks (Brownstein et al., 2018). Brownstein et al. (2018) suggested a lack of ability to apportion recovery between high intensity bouts was maybe linked to a young person's stage of cognitive development but couldn't conclude this from their study. It has been suggested previously that the stage of cognitive development affects how a young person paces during an exercise task (Micklewright et al., 2012). With those young people further along in their cognitive maturity having an increased capacity to pace themselves (Micklewright et al., 2012). No studies to date have investigated how cognition impacts young people's ability to plan and distribute effort during a high intensity intermittent running task.

Previously, research regarding pacing and high intensity intermittent running performance has focused on how physiological characteristics, for example, sub-maximal aerobic capacity, repeated sprint ability and anaerobic capacity discriminate between elite and non-elite players in sports such, as football and field hockey

(Elferink-Gemser, Visscher, van Duijn, & Lemmink, 2006; Visscher, Elferink-Gemser, & Lemmink, 2006). Recently, evidence supports the notion that higher order cognitive functions such as EF are extremely important for sports performance and may be a useful determinant of performance alongside physiological variables in young people (Verburgh et al., 2014).

EFs are a complex set of processes, said to contain four elements: initiation, sustaining, shifting and inhibition (Denckla, 1996). These elements provide the basis for higher order cognitive processes such as planning and reasoning (Diamond, 2013). During high intensity intermittent exercise, for example, match play, players are required to assess an exercise task and plan ahead to apportion effort effectively.

Such exercise tasks like match play require players to 'decide what to do' and 'how to do it' (Smits et al., 2014). This is particularly prevalent in match-play due to the ever-changing environment i.e. Game intensity, score line, opposition. Therefore, the brain must act as an information processing system to survey the game. The information processing approach is similar to that of the central control system which is responsible for decision-making during pacing (Smits et al., 2014). Complex environments such as match-play requires players to continually modify behaviour to fit the needs of the game. The ability to make decisions in regard to energy distribution during match-play involves the use of cognitive skills, such as, planning, reasoning and inhibition (Diamond, 2013). All of which are components of a specific higher-order cognitive process: EF.

For many years, it has been hard to define what controls cognitive skills such as planning and reasoning (Edwards & Polman, 2012; Marcora, 2008). It was not until recently that EF was suggested to play an integral role (Verburgh et al., 2014; Vestberg et al., 2012). Recent studies have investigated a link between EF and sporting performance (Verburgh et al., 2014; Vestberg et al., 2012). Vestberg et al. (2012) used the design fluency task to assess EF in adult football players and linked it to performance outcomes on the pitch. The results of the study showed a relationship between EF and the number of goals and assists during a football season. The study concluded EF can be used to predict future success in football. Further to this Verburgh and colleagues (2014) argued that the design fluency test was not an accurate indication of EF ability as it did not measure all components. Verburgh et al. (2014) used several tests of EF in their study on ball sport players with results indicating cognitive function tests predict success of ball sport players.

To date no study has investigated the link, if any, to pacing ability of young invasion games player’s and their EF capacity. Previous studies have looked at on field performance i.e. goals scores, and a player’s EF ability but none have linked this to pacing ability. Research on EF and on field performance has to date, also been carried out on adults, who are at a different cognitive stage to youth players. EF, like other cognitive functions, follows a development trajectory improving during adolescence (Anderson, 2002; Anderson et al., 2001). Micklewright et al. (2012) have already shown that a young person’s pacing ability is linked to their intellectual development with more intellectual developed children better able to pace during an exercise task than those in the earlier stages of intellectual development, suggesting pacing capacity increases linearly with age and EF development. It has already been shown that young invasion players are not as equipped to pace effectively during high intensity exercise as their adult peers (Gibson et al., 2018; Phillips, 2014). Therefore, providing basis for this thesis.

It is also important to note ss a young person is maturing external feedback is a useful tool for learning. Until young people have reached the formal intelligence stage of learning they find it hard to make internal representations of a task (Micklewright et al., 2012; Piaget, 1974). Something such as external feedback may be useful to these players. As with many skills the use of external feedback can aid performance. To date, pacing studies on feedback have solely focused on adult populations with feedback given as distance (Albertus et al., 2005). With distance feedback found to be not essential when developing an appropriate pacing strategy during cycling time trials (Albertus et al., 2005). As of yet no study has investigated how external verbal feedback may influence how a young person may pace during a high intensity intermittent running task. Furthermore, there is no evidence which shows whether young people’s EF ability impacts their response to external feedback during a high intensity intermittent running task.

Study Aims

The aim of this study is to investigate if EF ability is associated with how well youth invasion games players’ pace during a high intensity intermittent running task. This study will also look at how pacing performance may differ with the addition of external feedback.

It is hypothesised that an athlete's EF ability will correlate with their ability to pace effectively during the high intensity intermittent running task. It is also predicted that pacing performance will be greater in the feedback condition compared to the non-feedback condition.

3.2 – Methods

3.2.1 – Pilot Study

Prior to commencing this research, I conducted a pilot study on a sample population. Three male participants (age 23 ± 3) from Oriam (Scotland's Sports Performance Centre) Sports Science department participated in the study. All participants volunteered to be part of the pilot test and all of them stated that they were injury free at the start of data collection. The participants were briefed on the content of the study before taking part and asked to refrain from strenuous physical exercise 24 hours before testing.

The pilot test comprised the same procedure and equipment proposed for use in the experiment proper, except that there was not standardised warm-up for the participants before the start of each physical task. Due to participants age, maturity was not measured. All participants were familiar with the YoYo intermittent recovery, level 1 (YYIR1) test and running task prior to testing. Participants were from various sports, with only one actively taking part in team sports regularly.

Due to participants schedules, testing was completed over a two-week period at different times in the day which meant circadian rhythm may have impacted on results. Furthermore, the Iowa Gambling Task (IGT) was conducted in a communal office (i.e. not a quiet space) and participants were able to watch each other during the running trials.

No inferential analysis was carried out on the data due to the small sample size. The following can be taken from the raw data:

> 1.Total metres achieved was greater in the Feedback (FB) than in the no feedback (no-FB) condition.
> 2. For both conditions each of the participants completed all runs at or above their target speed, with the distribution of effort being greater in the FB condition than in the no-FB condition.
> 3. The running trials were split into quarters with a greater distribution categorised as those participants that have a similar or same number of runs in each quarter of the trial.

Fitness impacted the total distance achieved. Distance covered ranged from 480 - 920 metres (m) in the FB condition and 360 - 1040 m in the no-FB condition. The participant with the lowest YYIR1 score completed on average 400 m less in both trials than the middle scoring participant. Analysing individual times for each run showed participants tended to exceed their target speed by at least one second on average. Those participants who significantly exceeded their target speed, took much longer to recover, hence less metres covered. It is likely that if participants had maintained a speed closer to their specified target speed, recovery time would have been reduced and distance covered increased.

As initially mentioned only one participant regularly took part in team sports (football). This difference was apparent when testing, with the team sports player able to distribute their effort much more effectively than the non-team sports players. The participant who completed the most distance in both trials was a sprinter and had little team sports experience. Even though this participant completed the most distance (1040m), distribution of effort was more sporadic, particularly in the no FB condition with only 15% of runs completed occurring in the last quarter of the trial.

Throughout every trial and condition, all participants were present when another was testing, therefore they were able to see how other participants performed. This created a 'competition' environment as participants verbally stated they wanted to beat they other. Participants knew how great a distance others had achieved, creating a mentality of 'I need to get X amount of runs to beat Athlete Y'. This may have negatively impacted the results, due to participants wanting to beat other scores rather than thinking about planning and distributing their effort over the 10-minutes. Furthermore, participants asked and were told after the first trial how many successful runs and what distance they had covered, which inadvertently gave them a target for the second trial. In addition, the IGT was not conducted in the most appropriate environment. All tests were completed in a communal office in which there were many distractions.

No randomisation was used in the pilot study with all participants completing the FB condition first.

What information has been gained to inform the next stage?

After completing and analysing the pilot study the following measures will be taken to correct any issues that the pilot study has highlighted:

1. During the two running tasks participants will not be allowed to watch other players participating in the study thus eliminating some of the ‘competition’ aspect.
2. Participants were not informed till after the study had finished what distance they covered and their distribution of effort.
3. All data collection will be performed at the same time of day, in the same location and on the same surface for all running trials. This will minimise the effect of circadian rhythm and varying playing surfaces impacting on performance.
4. The IGT was conducted in groups of three in a quiet room with minimal distractions.

The two conditions for the running tasks were randomly assigned using an online tool to avoid any learned effects or researcher bias.

Furthermore, a standardised warm-up was devised and completed by each participant prior to any physical activity.

3.2.2 – Study Methods

Participants

Forty-four participants of mixed gender (age: 14.68 ± 0.8) from various club academies (Rugby, Football and Hockey) and independent schools in Edinburgh took part in the study. Of the forty-four, thirty-two (19 female & 13 male) complete data sets were collected after participant drop out, incomplete tests and equipment failings were accounted for. Participants regularly participated in team sports (Rugby, Football and Hockey) to a relatively high level (Academy or Sports Scholars). To be eligible for the study all participants had to be fit, healthy and injury free for at least three months prior to the start of the study (participants verbally gave this information). Before the study began participants (and parents) were informed of the procedures and gave written informed consent in accordance with the declaration of Helsinki. Ethical approval was obtained from Heriot-Watt University. Participants were requested to refrain from physical exercise 24 hours prior to testing sessions.

Procedures

The study incorporated a randomised repeated measures design. This design requires all participants to complete the task under multiple conditions/measures, with the order each participant completes a certain condition picked at random. Participants were asked to complete three separate testing sessions (YYIR1 and running task with and without feedback) within a three-week period with no more than one-week and minimum of 48 hours between each session.

During the study, data was collected for peak height velocity (PHV), yoyo intermittent recovery test level 1, two ten-minute running tasks and the Iowa Gambling task.

Prior to the start of the study all participants were habituated with the procedures and baseline data was collected for chronological age, stature and seated stature (metres), body mass (Kilograms). These measures allowed Maturity to be calculated. Mirwald et al. (2002) equation was used to calculate peak height velocity (PHV). PHV is a commonly used biological maturity marker, which gives an indication of maturation due to it providing maximal velocity of height during adolescence.

During the first testing session participants completed both the IGT and YYIR1.

Iowa Gambling Task

Bechara et al. (1994) IGT test was used to assess participant's EF. The IGT assess' a person's planning and 'hot' EF ability. As discussed in chapter 1, currently there is not an assessment of EF that taps into every one of its domains. The IGT was determined to be the most relevant to this study due to it measurement of planning ability.

A computerised version of the IGT task was used. The IGT was created on PsychoPi (version 3.0) and completed on a windows 10 laptop (Make/Model: Lenovo Thinkpad). The task presents participants with four decks of cards which vary in rewards and punishments. Participants select one of four card decks for a total of 100 trials. There is no limitation to how many times a participant is allowed to select from a single deck of cards, which is slightly different to the original IGT, which stopped card selections once 40 selections had been made from the same deck (Bechara et al., 1994).

Participants started with £2000, they were told the game was to continually select from the four decks, one card at a time until they made 100 selections. The aim being to win as much money as possible. After each card selection the participant was told how much money they have won or lost with a running total also present. Decks A and B yields £100 while decks C and D yield £50. Decks A and B produce a higher yield, but they also provide a higher chance of punishment. For example, after participants have selected ten cards from decks A or B they have won £1000 but they have been punished five times (-£1250), which means they incur a net loss of £250. Decks C and D on the other hand, will produce £500 after 10 selections but will only incur a loss of £250. Thus, decks A and B are regarded as the disadvantage decks. A participant's performance in the test is judged based on net money at end of test, number of switches from good to bad decks and total number of switches. All participants were uninterrupted during the test and performed it in a quiet area with no distractions.

YoYo Intermittent Recovery Test

30 minutes after completion of the IGT participants completed the YYIR1 test. This required participants to run 40 metre shuttles with a 180-degree change of direction with a 10 second recovery in between each shuttle to the timing of an audio signal. The test gradually increases running speed until volitional exhaustion. Set-up and procedures followed previous guidelines (Bradley et al., 2011; Krustrup et al., 2003). The test was terminated when participants reached volitional exhaustion, or they were unable to keep time with the audio signal. All participants received two warnings regarding keeping up with the audio signals before they were pulled from the test. YYIR1 was chosen for this study over level 2 due to the participant sample. The YoYo intermittent recovery test is a widely used assessment of aerobic capacity. Unlike the commonly known bleep test, the YoYo intermittent recovery test employs set recovery times of 10 seconds between each run. The test comprises of two levels (level 1 & level 2). The YYIR1 is designed to test athletes that possess a lower aerobic capacity i.e. recreational or younger athlete; which this studies population represented. Total distance and level were recorded, and the information used in subsequent trials. The YYIR1 was used in the current study as it was highly relatable to the intermittent nature of the subsequent running tasks. The level achieved and hence running speed of that level in the YYIR1 was then used as each participant's 'target' speed for the subsequent running assessments.

Running Task

Participants each completed two 10-minute running tasks under two conditions. The task involved completing a similar 40m shuttle task as in the YYIR1. Unlike the YYIR1 no audio signals were employed to indicate when a participant should run, instead participants self-selected when to run and their recovery periods. They were told the aim was to complete as many runs as they could in the 10-minute period. However, they were also informed they had to run at a certain target speed for their run to count. Failure to hit the target speed for a run would result in a no-run; i.e. they would have expended energy on completing 40m that did not count toward their total for the 10 min. Target speed for each participant was determined by their performance in the

YYIR1. The duration between the audio-signals on the last level they achieved on the YYIR1 was their target speed. For example, a participant that achieved level 15 on the YYIR1 had 9.6 seconds to run the 40m shuttle.

Running Speed was measured using infrared timing gates (SWIFT SpeedLight: Australia) positioned at the start/finish line. Prior to the start of each condition participants were allowed up to three practice runs to gauge their required running speed.

Conditions

The running task was performed under two conditions, which are as follows:

1) In the feedback condition participants were told a simple ‘yes’ or ‘no’ after each run to indicate whether they had hit the required target speed or not. Additionally, participants were informed at regular intervals (2.5/5/7.5 minutes) how much time had elapsed.

2) In the no feedback trial, it was not indicated to participants if they had achieved the target speed after each run. The only information they were given was the start and end of the test.

The order of conditions was randomly selected. All running tasks were conducted outdoors with each participant completing all tests on either a grass surface or a synthetic pitch (Astroturf). Before any physical exertion participants completed a standardised warm-up following the RAMP framework (Jeffreys, 2007). Additionally, participants completed all tests at the same time of day to minimise the influence of circadian rhythm on performance.

Iowa Gambling Task

The number of times participants switched decks was recorded alongside total money. Performance was defined as the number of good selections per each twenty-five card selections, total money won and total number of switches.

YYIR1

Performance was determined by the last completed level achieved before exhaustion.

10-minute running task

Total distance (m) covered was calculated alongside total successful runs. The task was split into four 2.5- minute quarters with percentage successful runs, total successful and unsuccessful runs and total recovery duration calculated for each.

Statistical Analysis

Statistical analysis was carried out on SPSS (IBM, version 22.0) and JASP.(version 0.10.2) Significance level was set at 0.05. Descriptive statistics were represented as Mean ± SD unless stated otherwise. All data was checked for normality using the Shaprio Wilks test, if sphericity had been violated the greenhouse Geiser column was used. A 2 × 4 repeated measures ANOVA was used to determine within and between subject factors for percentage of successful runs, number of successful runs, number of unsuccessful runs and total recovery duration for each quarter between the two conditions (FB and no-FB). In the event of a significant main effect, simple main effects analysis was performed on the data. Partial ETA squared was used to quantify the effect size.

Pearson moment correlations were used to determine associations between physiological variables: gender and distance covered in the yoyo test, yoyo distance and total distance achieved in the running task.

IGT Data. Pearson moment correlations were carried out for the following:

1. Total money and number of good card selections
2. Number of switches and number of good card selections

To compare the IGT with the running task data Pearson moment correlations were used. The IGT data was split into four quarters, with 25 card selections in each. The number of card switches and the number of good card selections was analysed and recorded for each quarter. Correlations were carried out to determine if there was any association between IGT performance and a participant's performance in the running task. To do this a Pearson's moment correlation were performed on the data: the number of good selections in each quarter of the IGT was correlated with its corresponding quarter in the running task.

3.3 - Results

3.3.1 - Descriptive Statistics

Running Performance

Performance measures during the running trials are displayed in Table 1. Mean distance covered was greater in the YYIR1 test (968m) (the range of a YYIR1 test is 40 – 4460m) than in either of the running task conditions feedback (932m) and no feedback (914m). With average distance achieved in the feedback condition greater than that in the no feedback condition. A greater range was seen in the YYIR1 distance than the distance achieved in either conditions. With the no feedback condition showing the largest distance range.

Table 1: Mean, SD and range of all physiological variables

	Age (years)	YYIR1 Distance (M)	Distance Covered (FB)	Distance Covered (no FB)
Mean	14.68	968	932	914
SD	0.81	305	173	186
Range	13 - 16	480-1720	560-1200	520-1240

Psychological Performance

Performance in the IGT are provided in table 2. As it can be seen participants on average finished the IGT with less money (£1614) than they started the task with (£2000).

Table 2: Mean, SD and range of Iowa Gambling Task variables

	Number of Switches	Number of Good Selections	Money Won (£)
Mean	79	47	1614
SD	17.8	9.4	590.1
Range	31-99	23-72	-50-3250

Figure 1 shows that as participants progressed through the IGT the average number of advantageous choices increased linearly, with the biggest difference in advantageous selections seen between the first and second quarters of the task.

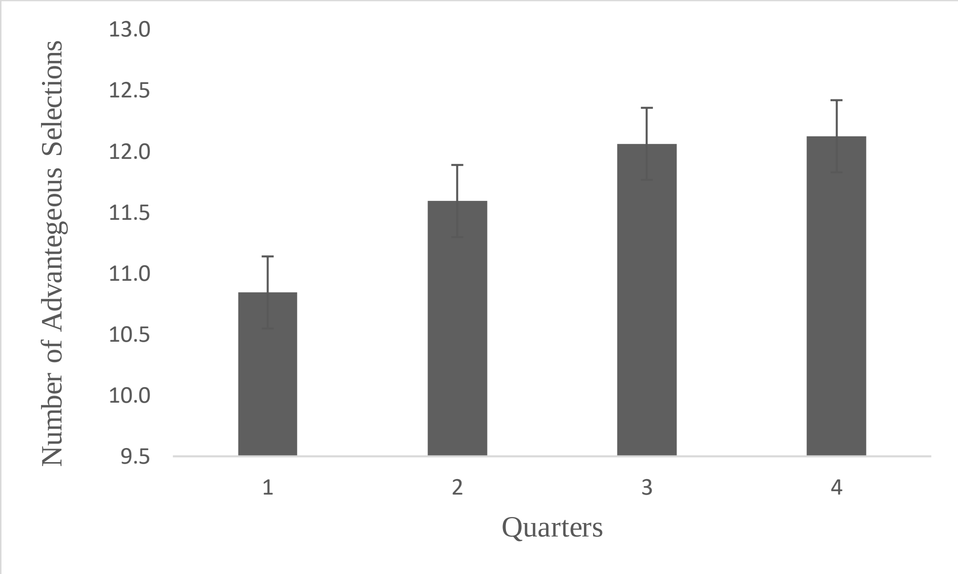

Figure 1. Average number of advantageous selections made in each quarter in the IGT (error bars represent 1 standard error).

Furthermore, figure 2 shows the average number of switches between decks varied. The graph shows number of switches, but it does not specify if these switches were between the two good decks or between the good and bad. Figure 1 seems to suggest the increased number of switches seen in quarter four were more frequently between the two good decks as the number of switches increased (figure 2) but the number of advantageous selections also increased (figure 1).

Table 3: Mean of every variable for each of the four quarter in the running task

	Feedback					No Feedback				
	2.5	**5**	**7.5**	**10**	**Avg**	**2.5**	**5**	**7.5**	**10**	**Avg**
Total Number of Runs	7.25	5.53	4.97	5.34	5.77	7.31	5.38	5	5.06	6.95
Total Successful	5.84	4.78	4.34	4.81	4.94	4.71	3.38	3.72	3.86	3.92
Total Unsuccessful	1.41	0.75	0.66	0.56	0.84	2.34	1.78	1.03	1.03	1.55
Percentage Successful (%)	82.12	86.95	87.38	90.12	86.64	68.78	64.55	76.94	80.31	72.65
Total Recovery Time (S)	81.4	100.96	108.84	87.12	94.58	82.27	100.66	104.34	92.88	95.04

Table 3 shows the mean for each of the variables measured in each quarter (minutes elapsed) of the running task for both conditions.

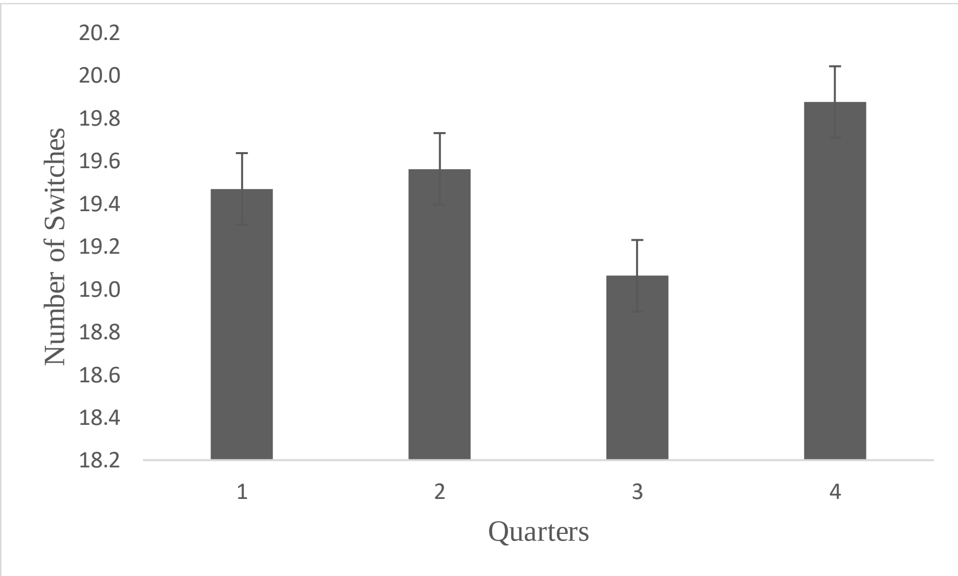

Figure 2. Average number of switches in each quarter (every 25 card selections) in IGT (error bars represent 1 standard error).

3.3.2 - Inferential Statistics

ANOVAs (2 x 4) revealed significant differences between conditions for the following variables: Total Successful runs (F (1,31) = 13.062, p = 0.001, η^2 = 0.296), total unsuccessful (F (1, 31) = 3.318, p = 0.078, η^2 = 0.097) and percentage successful (F (1,31) = 6.471, p = 0.016, η^2 = 0.173). It did not show significant differences for total runs (F (1,31) = 0.253, p = 0.618, η^2 = 0.008) and total recovery (F (1,31) = 0.094, p = 0.761, η^2 = 0.003).

Comparison of running task conditions

Total runs. Using total runs as the dependant variable, an ANOVA (2 × 4) with condition (Feedback and non-feedback) as a within-subjects factor and quarters as a within-subjects factor revealed a significant main effect for quarter (F (3,93) = 67.583, p = <.001, η^2 = 0.686) and for condition (F (1,31) = 0.253, p = 0.618, η^2 = 0.008). Showing the feedback condition to be greater than the non-feedback condition. There was no significant total runs x condition interaction (F (3,93) = 0.421, p = 0.699, η^2 = 0.015).

Simple main effects analysis revealed no significant difference in total successful runs achieved between the two conditions for the first (F= 0.034; p = 0.855, d = 0.042), second (F=0.431; p = 0.516, d = 0.104), third (F= 0.021; p = 0.887, d = 0.021) and fourth (F=1.256; p = 0.271, d = 0.187) quarters.

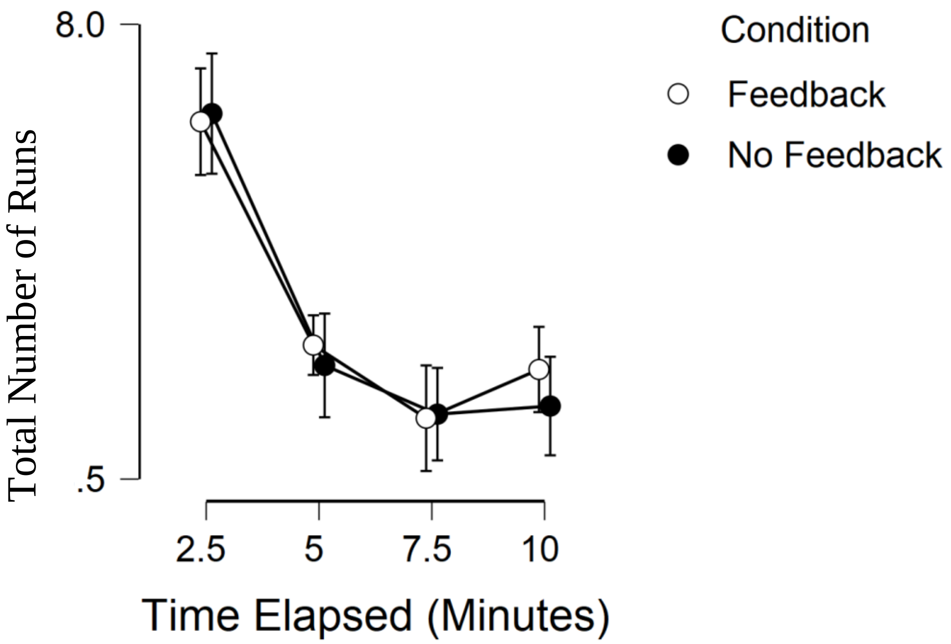

Figure 3. Total number of runs achieved per quarter for feedback and no feedback condition.

Total successful runs. Using total successful runs as the dependant variable, an ANOVA (2 × 4) with condition (Feedback and non-feedback) as a within-subjects factor and quarters as a within-subjects factor revealed a significant main effect for total quarter (F (3,93) = 17.909, p = <.001, η^2 = 0.366) and for condition (F (1,31) = 13.062, p = 0.001, η^2 = 0.296). Showing the feedback condition to be greater than the non-feedback condition. There was no significant total successful runs x condition interaction (F (3,93) = 1.454, p = 0.232, η^2 = 0.045).

Simple main effects analysis revealed a significant difference in total successful runs achieved between the two conditions for the first (F= 6.357; p = 0.017, d =0.540), second (F = 14.670; p = <.001, d = 0.675) and fourth (F=8.908; p = 0.005, d = 0.450) quarters. No significant main effect was found for the third quarter (F = 3.539, p = 0.069, d = 0.300).

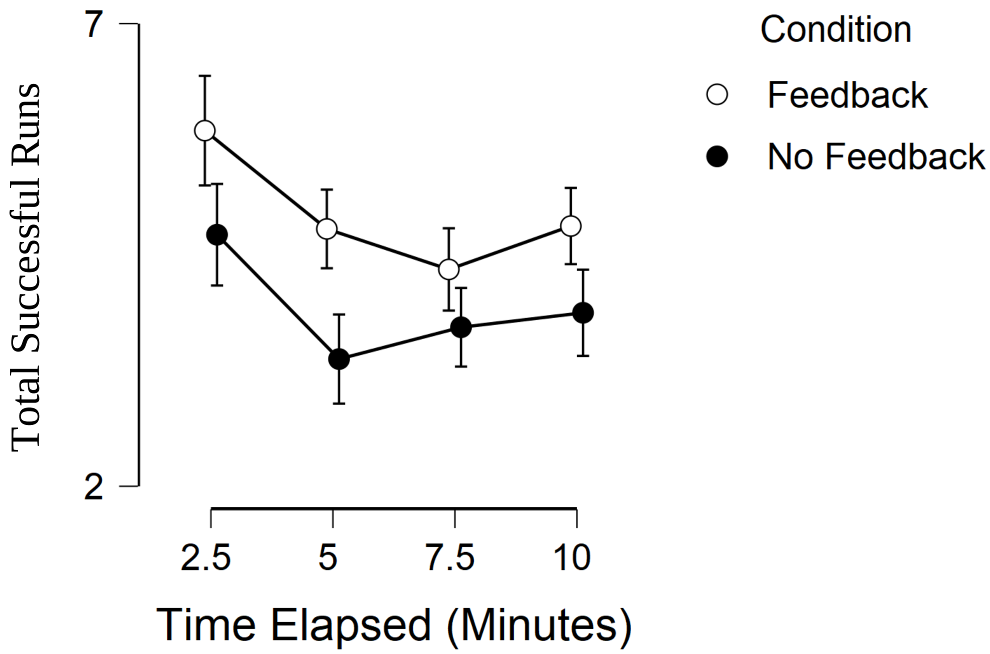

Figure 4. Total successful runs per quarter for feedback and no feedback condition.

Total unsuccessful runs. Using total unsuccessful runs as the dependant variable – an ANOVA with condition (Feedback and non-feedback) as a within-subjects factor and quarters as a within-subjects factor – revealed a significant main effect for total unsuccessful runs (F (3,93) = 8.833, p = <.001, η^2 = 0.222) and for condition (F (1, 31) = 3.318, p = 0.078, η^2 = 0.097). Showing the feedback condition to be greater than the non-feedback condition. There was no significant total unsuccessful runs x condition interaction (F (3,93) = 1.295, p = 0.281, η^2 = 0.040).

Simple main effects analysis revealed a significant main effect found between conditions in number of unsuccessful runs for the second quarter (F = 5.356; *p* = 0.027, *d* = 0.396). No Significant main effect was found for the first (F = 2.627; p = 0.115, *d* = 0.360), Third (F = 0.959; p = 0.335, *d* = 0.144) and fourth Quarters (F = 1.313; p = 0.261, *d* = 0.180).

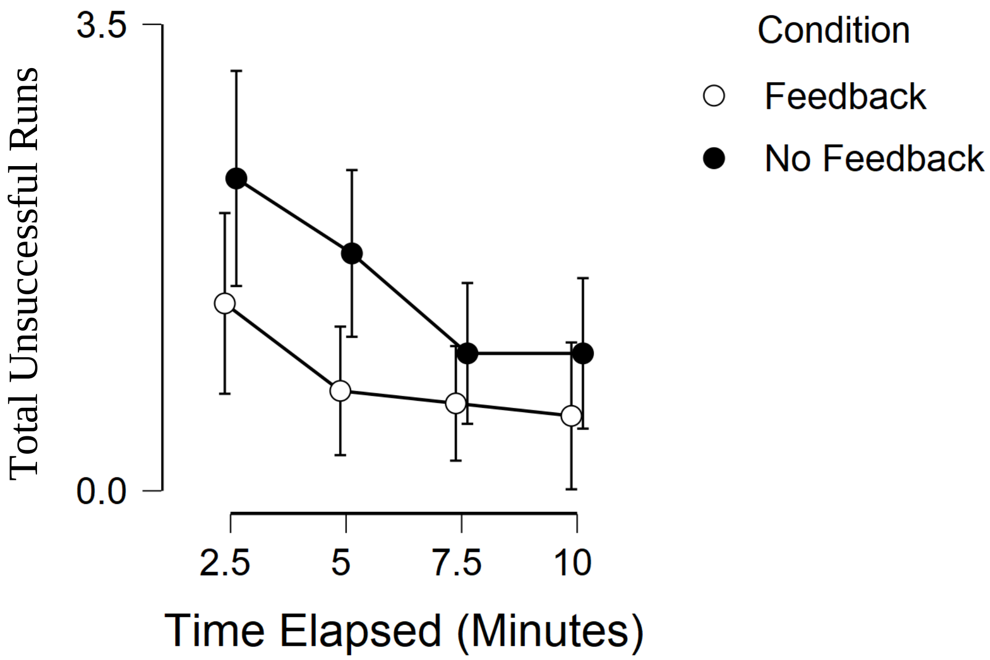

Figure 5. Total unsuccessful runs per quarter for feedback and no feedback conditions

Percentage successful runs. Using percentage successful runs as the dependant variable, an ANOVA with condition (Feedback and non-feedback) as within-subjects factor and quarters as a within-subjects factor revealed a significant main effect for percentage successful runs (F (3,93) = 4.160, *p* = 0.008, η^2 = 0.118) and for condition (F (1,31) = 6.471, *p* = 0.016, η^2 = 0.173). Showing the feedback condition to be greater than the non-feedback condition. There was no significant percentage successful runs x condition interaction (F (3,93) = 2.185, *p* = 0.095, η^2 = 0.066).

Simple main effects analysis revealed a significant main effect found between conditions for percentage successful runs for the second quarter (F = 10.527; *p* = 0.003, *d* = 0.612). No Significant main effect was found for the first (F = 3.567; p = 0.068, *d* = 0.364), Third (F = 2.458; p = 0.127, *d* = 0.285) and fourth Quarters (F = 3.760; p = 0.062, *d* = 0.268).

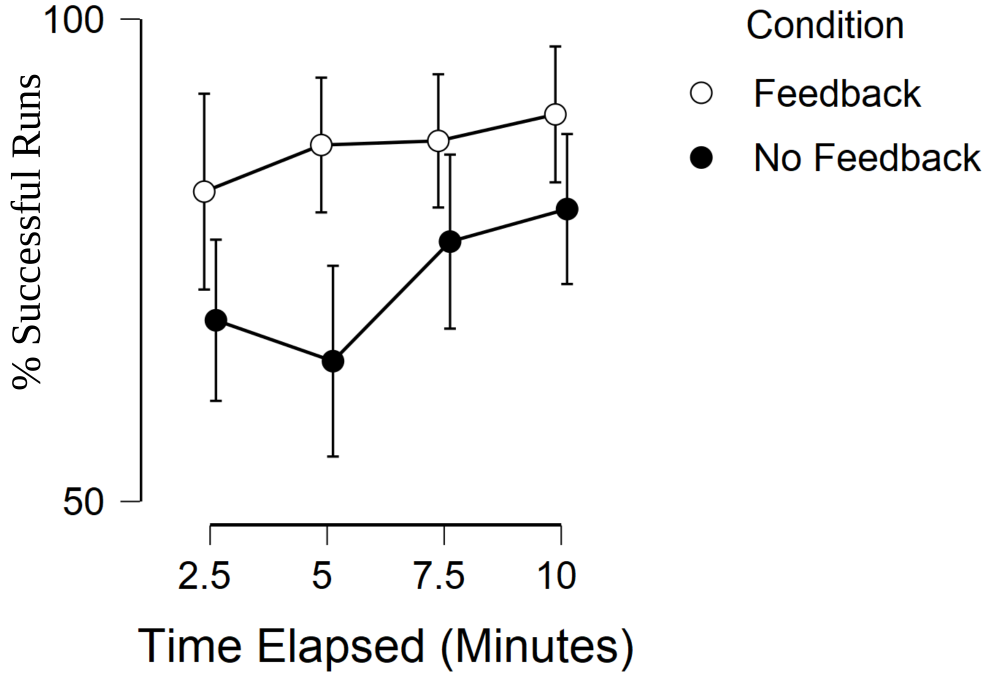

Figure 6. Percentage Successful runs per quarter for feedback and no feedback conditions

Total Recovery time. Using total recovery time as the dependant variable, an ANOVA with condition (Feedback and non-feedback) as within-subjects factor and quarters as within-subjects factor revealed a significant main effect of total recovery time (F (3,93) = 24.919, *p* = <.001, η^2 = 0.446). Showing the feedback condition to be greater than the non-feedback condition. No significant main effect was found for condition (F (1,31) = 0.094, *p* = 0.761, η^2 = 0.003) or total recovery time x condition interaction (F (3,93) = 1.161, *p* = 0.329, η^2 = 0.036).

Simple main effects analysis revealed no significant main effect found between conditions and recovery time for the first (F = 0.097; p = 0.758, *d* = 0.042), second (F = 0.004; p = 0.951, *d* = 0.015), Third (F = 1.806; p = 0.189, *d* = 0.216) and fourth Quarters (F = 2.914; p = 0.098, *d* = 0.275).

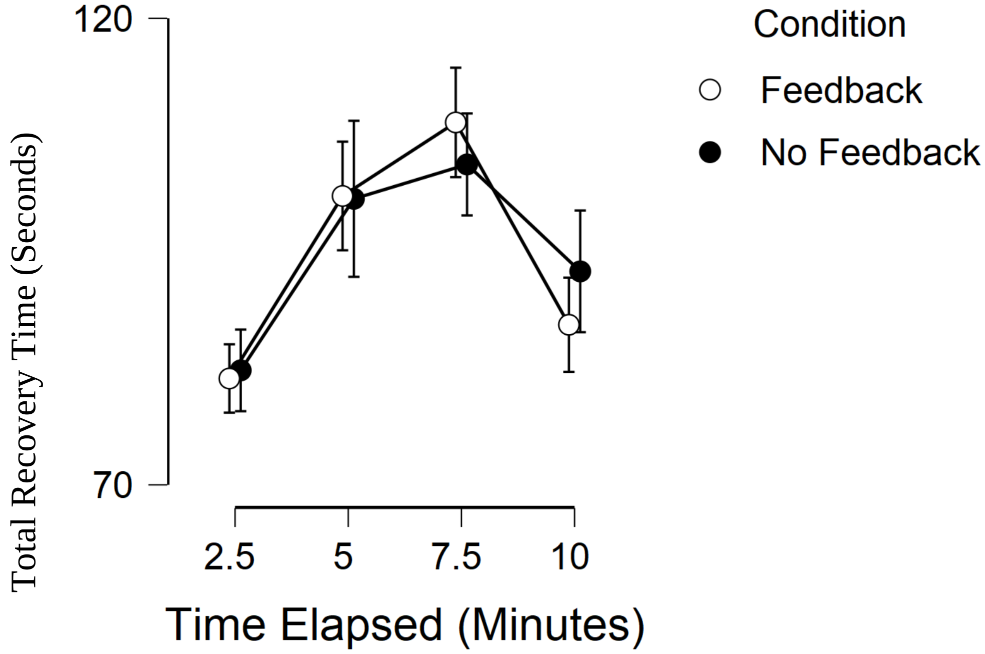

Figure 7. Total recovery time per quarter for feedback and no feedback conditions

Relationship between IGT and running task performance

Pearson's moment correlations showed a strong correlation between total money and number of good selections in the IGT (r = 0.665; p = <0.001).

No significant correlation was found for the IGT and number of successful runs for the first (r = 0.008; p = 0.961), second (r = 0.0096; p =0.578), third (r = 0.018; p = 0.915) and fourth (r = 0.272; p = 0.108) quarters. Results of the IGT were correlated with the number of successful runs as they represented the 'good' picks in each quarter of the IGT and the 'good' runs in the running task.

Influence of Maturity

Mean age of participants was 14.68 ± 0.8 years, with a mean PHV of 1.88 ± 1.16. Maturity data showed no significant correlation for PHV and IGT performance (r = -0.025, p = 0.888).

No significant correlation was found for total successful (r = -0.216, p = 0.206) or unsuccessful runs (r = 0.060, p = 0.727) and PHV.

Additional Analysis

YYIR1 distance was found to be positively correlated with distance completed in the running tasks (*r* = 0.630; *p* = <0.01). There was no significant correlation found between gender and YYIR1 distance (*r*=0.295; *p*=0.102), meaning gender had no role to play in amount of distance covered intermittent high intensity running task.

CHAPTER 4 - DISCUSSION

The findings of this study suggest no link between a young athlete's ability to pace and their performance in a non-sport specific cognitive task (IGT). With no significant difference found between the number of successful runs in each quarter of the task with the corresponding quarter of the IGT. The study also suggests no link between biological maturity and EF ability (p = 0.888).

A key finding of this study is that participants pacing performance was significantly greater in the feedback than the non-feedback condition i.e. they completed more successful runs with a more even distribution of runs in each quarter of the running task. The results indicate an individual's ability to adopt an effective pacing strategy is benefitted by the addition of external feedback. This difference can be seen in total successful runs, percentage successful, with performance in these variables being greater in the feedback than non-feedback condition. Results also indicate that one piece of feedback given early on in a task may be just as effective as continuous feedback throughout the whole duration of a task. Showing that when feedback was given at the end of the first quarter performance improved, while in the non-feedback group performance decreased.

3.4.1 – Is There a Link Between EF Ability and Pacing Ability?

The current studies results suggest that the IGT was not a good indicator of pacing performance. However, as the IGT is not the definitive test of EF ability it may be that other measures of EF may have been better predictors of performance.
Interestingly, the results of the IGT test alone did not concur with previous research (Almy, Kuskowski, Malone, Myers, & Luciana, 2018; Mussey, Travers, Klinger, & Klinger, 2015). It was expected that as participants progressed further into the IGT they would notice a pattern i.e. good and bad decks, with an increase in the number of good selections increasing and bad selections decreasing the further into the task with eventually participants only picking from the good decks (Bechara et al., 1994; Mussey et al., 2015). This pattern in previous research shows a learnt effect with participants adjusting their selections based on the environment and their ability to make the correct decisions improving (Mussey et al., 2015). This pattern of results was not fully seen in the current study. By the fourth quarter of the IGT, participants were making more selections from the good decks, but they were not solely picking from these decks which previous research had indicated (Bechara et al., 1994).

The study found the IGT did not show any sort of correlation with how well participants paced (characterised by how many successful runs were achieved in each quarter of the task) in the running tasks used in the study. These results could suggest that pacing ability is not affected by a young person's EF ability. It was expected that those participants who scored higher in the IGT would be-able to perform more successful runs with less time wasted on unsuccessful runs by allocating recovery in an effective manner. Unfortunately, this did not occur. However, as previously stated EF is a very hard domain to measure/assess, making it very hard to draw a firm conclusion from the results of this study. The IGT aims to test decision-making and is considered a form of 'hot' EF. 'Hot' EF is EF that is associated with the orbitofrontal cortex and a person's ability to make effective decisions (Kerr & Zelazo, 2004). The IGT has been used in clinical neuroscience but as of yet it has not been used in a sport specific study (Almy et al., 2018). It was thought the IGT to be the most relevant test for this study due to its association with decision-making. It is possible that due to its non-sport-specific nature it did not give the results desired. It is possible that off-field, everyday EF ability displayed in such tests of the IGT does not indicate a person's on-field decision-making capacity.

Due to EF having so many domains, the IGT does not tap into every one of them which might have been the cause of inconclusive results. However, it was decided before the start of the study that the domain of EF that the IGT tested was the most relevant to the high intensity intermittent exercise task used in the study. It is important to note that, even if the study had incorporated a variety of different EF tests it may still have produced insignificant results. As of yet no true test of EF has been invented, (whether that is non-sports specific or sport specific) which means it is increasingly hard to test but you can look for patterns within these tests which might show the desired link.

Even though there was no significant correlation between the IGT and pacing performance. Results did show that as participants progressed through the IGT, their number of good selections increased slightly suggesting some sort of learning effect was present. This change in strategy further into the task is a similar pattern to that seen in participants pacing performance with participant's percentage of successful runs increasing as the task progressed. Successful runs increased and total runs decreased, which means participants increased their recovery time between bouts of effort as the task progressed. This is similar finding to that of other studies looking at self-selected recovery times during repeated high intensity bouts in youth populations (Brownstein et al., 2018; Gibson et al., 2017). Similarly these studies found that youth populations were less able to apportion effort using self-selected recovery with increased running performance seen at the end of a repeated sprint task when participants had taken a slightly longer recovery period (Brownstein et al., 2018; Gibson et al., 2017).

The change increase in successful runs as the task progressed also shows a slight learning effect from both the IGT and pacing task albeit learning during the IGT did not occur in the way previous research indicated. Unfortunately, this pattern seen in both the IGT and running task was not significant enough to conclude a link between EF and Pacing ability.

The task itself may not have been the problem but the population that was used in the study. Previous research using the IGT stated it had been carried out within young population sample (8-23 years) (Almy et al., 2018; Kerr & Zelazo, 2004; Smith, Xiao, & Bechara, 2012). Even though the IGT has been carried out with ages that span across the whole of adolescence, some research has noted that fewer disadvantage decisions (selection from the ‘bad decks’) are made between ages 16-18 than in younger populations (Almy et al., 2018). It is quite possible that the younger participants did not fully understand the task or did not have the cognitive capabilities to produce the learned effect required. Therefore, with an easier or different EF task a correlation may have been seen with running performances.

Previous research using the IGT as a measure of EF have tested participants with the task on numerous occasions (Almy et al., 2018; Tuvblad et al., 2013). For example, Tuvblad et al. (2013) tested twins using the IGT on numerous occasions from early adolescence to 18 years, with performance improving as participants got older. As with most things, it has been found the more a person does a task the better they become at it. In the current study the participants were only tested using the IGT once, as it was thought that by only testing once would give a truer reflection of each participants EF ability.

3.4.2 - What Pacing Strategy was employed in this Study?

Participant’s fitness levels were not an influencing factor when it came to pacing performance in the two running tasks, with participants on average covering more distance in the running task than in the yoyo test. This could be attributed to YYIR1 test having set recovery periods of 10 seconds between shuttles, meaning participants had to complete the next shuttle even if they did not feel they had had adequate recovery time or vis versa. However, it should also be noted that the average time for the YYIR1 test in this study was eight minutes and ten seconds, which is shorter than total time in the running task.

It can be seen from figure 3 that a parabolic pacing strategy was adopted by participants in the two running tasks in this study. With participants setting off fast and adjusting their strategy accordingly. This parabolic pacing strategy was demonstrated by the total number of runs participants completed in each quarter of the exercise task. The total of number of runs slowly decreased in each quarter, with the exception of quarter four in the feedback group where an 'end spurt' occurred. This concurs with existing data in children which shows they produce a more reactive pacing strategy and modify this strategy as a task progresses (Micklewright et al., 2012). This strategy differs from adults who have been found to be more cautious and produce a more conservative pacing strategy (McEwan et al., 2018; Phillips, 2014). Both Phillips (2014) and McEwan (2018) found that when adults self-selected their own recovery during high intensity intermittent exercise, they over-estimated the amount of recovery required.

Even though the total number of runs decreased as the task progressed, the percentage of successful runs slowly increased. This suggests that participants were running less but they were becoming more efficient with how they expended their effort as their percentage of successful runs increased. This concurs with previous studies, which has shown that the further into an exercise task an athlete gets the better able they are to determine end point alongside an increased capacity to interpret afferent signals (Edwards & Polman, 2013).

It is common during the latter stages of a prolonged task for pacing strategy to change i.e. end spurt. This phenomenon is when an athlete realises, they have extra energy towards the end of a task (as they have not paced most effectively or saved energy on purpose) so, a sudden increase in performance is seen (Lambert et al., 2005). For example, Micklewright's (2010) study on cyclists pacing strategies, revealed there was an end spurt during the later stages of the task in this study in the feedback condition. It can be seen from figure 3 that an 'end spurt' was employed in the 4th quarter of the exercise task in the feedback condition only. An 'end spurt' is usually associated with athlete's increased capacity to interrupt afferent signals, so adjust pacing strategy as end point nears due to the decrease in the likelihood of premature fatigue occurring (Micklewright et al., 2010; R. Tucker, 2009a).

The presence of an 'end spurt' in the feedback condition suggests that participants were not totally effective in their pacing strategies. In the feedback group after the last piece of time feedback was given the total number of runs significantly increased. This sudden increase in runs shows the participants had a 'lot left in the tank' therefore had adopted a slightly conservative pacing strategy.

Anticipation and Pacing Strategy

The total runs completed were greatest in the first quarter for both conditions. Interestingly total runs were still greater than the no feedback condition even before any feedback was given, the effect size was small. Suggesting that some other factor affected performance. There are several reasons why this occurred, one of which is anticipation of the task/event. All participants were told prior to the start of the task which condition they would be partaking in. It is likely prior knowledge of the task impacted pacing strategies. For example, the feedback group knew that external feedback would be given so they would be-able to adjust strategy better after feedback was given, if necessary.

Pacing strategy has previously been seen to be affected by prior knowledge of a task and its demands (Billaut et al., 2011; Smits, Polman, Otten, Pepping, & Hettinga, 2016). This prior knowledge creates anticipation of a task, which has been found to impact pacing strategies. Research on pacing in the heat shows anticipation plays a role in an athlete's regulation of exercise intensity (Marino, Lambert, & Noakes, 2004). Adjustments to pacing strategies in the heat have been found to occur before physiological variables have impacted body temperature (Marino et al., 2004; R. Tucker, 2004). Tucker et al. (2004) found power output and skeletal muscle activation was significantly reduced in the first 6km of a 20km time trial when performed in the heat compared to the cool. Similarly, Marino et al. (2004) suggested an anticipatory system, finding African and white Caucasian athletes pacing strategies differ in the heat.

The same patterns can be seen in the data set for this study. Data suggests that participants underestimated the demands of the task in this studies task so went off too hard in the beginning (maybe due to anticipation of the task) and had to re-assess their strategy as the task progressed. As it would have been expected, in the feedback condition participants were able to adjust their strategy quicker, with a drop of total runs and an increase in percentage successful runs in the second quarter. In the no feedback condition strategy was adjusted but it took till the third quarter, this was due to the no feedback group having only intrinsic factors as a source of feedback.

3.4.3 - Did the Presence of External Feedback Impact Pacing Strategy or Performance?

As hypothesised, in the present study external feedback improved pacing strategy in comparison to the no-feedback. When external feedback was present the number of successful runs was significantly greater in quarters one, three and four and significantly less unsuccessful runs were seen across all four quarters, suggesting participants pacing performance was more effective when feedback was given at regular increments. Conversely, when feedback was not present participants were still able to adapt and improve their pacing performance (increase in percentage of successful runs) as the task progressed, suggesting afferent and efferent signals played a role in pacing performance (Edwards & Polman, 2013).

Previous research has displayed that implementing feedback such as distance feedback during an extended exercise task resulted in a significant increase in performance (Faulkner, Arnold, & Eston, 2011). The present study found that during the feedback condition, percentage of successful runs in each of the four quarters of the task was significantly greater resulting in a better pacing performance. During a prolonged high intensity task, the addition of various forms of feedback increases performance as when an athlete is uncertain of the end point of time elapsed in a task, they are more likely to adopt a pacing strategy, such as ‘slow start’ pacing strategy (Tucker, 2009a). Performance has been seen to decrease even when no difference in perceptual or physiological values are seen in feedback and no feedback conditions (Faulkner et al., 2011), suggesting athletes are likely to perform at a lower intensity when feedback is not present.

With no feedback athletes have been found to struggle to conceptualise the duration of a task, which affects the way in which they pace themselves (Faulkner et al., 2011). It can be seen from this study that as participants progressed in the task they were found to be-able to improve their performance i.e. increased percentage of successful runs in each quarter. Even though, participants total runs decreased as the task went along the increase in percentage of successful runs shows that a participant was learning if they took a longer recovery period between runs, they were more likely to hit their target speed and produce a successful run. Therefore showing, participants were able to improve their strategy over time. However, this suggests participants failed to determine the demands of the whole task prior to starting.

Uncertainty of end point changes an athlete's pacing strategy due to the uncertainty of the length of task (Baden et al., 2005). During Micklewright et al. (2010) study, it was found that during a 20km cycling time trial, pacing strategy was significantly altered during the false positive feedback group even though completion time, average power and speed was not significantly different. Mauger, Jones and Williams (2010) showed that when cyclists were provided with inaccurate and accurate distance feedback during a 4km time trial, time to completion was significantly faster in the accurate distance feedback group.

Fatigue

Furthermore, during prolonged exercise, it is said athletes will adopt a pacing strategy aiming to optimise performance and minimise the onset of premature fatigue (St Clair Gibson et al., 2006). As previously stated, it is thought participants expended too much effort in the first quarter of the task creating premature fatigue.

Recently the importance of fatigue in pacing has been investigated, with evidence suggesting that it is changes in the peripheral physiological systems act as afferent signals, which tell an athlete they cannot keep up the same intensity for the whole task (Lambert et al., 2005; Noakes, St Clair Gibson, & Lambert, 2005). This phenonmon can be seen in the current study as total number of runs significantly decreased for both conditions after quarter two of the task; suggesting in both conditions' participants 'went off too hard'.

One of the reasons for this presence of early fatigue relates back to participants failure to conceptualise the demands/end of the task. End point in this study was determined by time rather than distance. It has been found that school age children find it harder to determine the demands of a task when end point is determined by spatial rather than temporal cues (Chinnasamy et al., 2013). It was thought with the sample population being in late adolescent that time (temporal cue) being an end point determinant would work. The studies population were aged 13-16, so according to Piaget's theory of intellectual development participants should all have been in their formal intelligence years, meaning they in theory should be-able to successfully anticipate the demands of a task and form internal spatial representations (Chinnasamy et al., 2013). This seems to have not been the case in this study. In particular reference to the no feedback condition, participants struggled with pacing, which could be associated with their only monitoring of the task being through chromesthesia (Perception of time elapsed) (Chinnasamy et al., 2013). In the present study, it is shown that participants pacing was significantly greater in the feedback condition where time elapsed and performance variables were given than the no feedback group, where end time was the only variable given. However, we cannot deduce whether such an effect was due to end point given as a temporal rather than spatial cue.

Can Performance Improve After One Piece of Feedback?

Previously it has been suggested that young people are able to improve or adjust pacing performance after gaining only one piece of information (Lambrick, Rowlands, Rowland, & Eston, 2013). In the current study, the percentage of successful runs significantly increased between the first and second quarter in the feedback condition, after which performance increased linearly until the end of the task but at a much slower rate. Suggesting participants were able to effectively adjust their performance after just one piece of feedback.

Previously, it was found adults can create a performance template after repeated bouts of exercise (Foster et al, 2003). This is attributed to a 'learned' effect due to task familiarisation (Foster, Schrager, Snyder, & Thompson, 1994). Recently, Lamberick and colleagues (2013) found that young people are also able to produce a pacing template after only one bout of unfamiliar exercise. The study found after young people had completed an initial task (800m race), pacing strategy was significantly improved during subsequent repeated running tasks (Lambrick et al., 2013). This occurred even though the young people had never experienced the exercise task before. Without prior experience, young people were able to produce an effective pacing strategy and regulate pacing to produce an 'end spurt' (Lambrick et al., 2013). This effect was seen in the current study, with young people able to adjust their pacing strategy before verbal feedback measures were given, suggesting young people can listen to intrinsic mechanisms to change pacing strategy for the most effective performance. Even though no physiological measures were taken in the current study, this intrinsic mechanism claim can further be backed up as the results showed that after the 2^{nd} quarter in the non-feedback condition participants were able to adapt their strategy to produce a more effective performance in the final two quarters of the task with only the aid of intrinsic feedback. Therefore, suggesting that one piece of feedback given early on in a prolonged task may be just as effective as given continual feedback throughout the whole task.

Recovery

It was found that there was no significant difference in average recovery times between quarters for each of the two conditions. This is interesting as it has been suggested previously that individuals with higher levels of fatigue would increase their recovery time during high intensity intermittent exercise (Glaister et al., 2008). As previously mentioned, fatigue seemed to be more prominent in the non-feedback group as it took longer to adjust pacing strategies. According to previous evidence higher fatigue would have meant higher average recovery lengths in the non-feedback condition, this did not occur in this study.

The results also indicate that total runs reduce in quarter two of the task for both conditions, with total successful runs increasing. This suggests that participants were running less but achieving more success, this can be attributed to a longer recovery taken between runs. It has been seen that youth adopt a 'reactive' pacing strategy. It has been found that young people will start an exercise task at a high intensity and then decline as the task progresses (Micklewright et al., 2012). In this study it can be seen participants started with a high intensity taking short recovery periods but as the task progressed, they adopted a slightly more conservative strategy and increased their recovery periods. This was expected as previous research has shown that young people cannot regulate recovery to the same extent as adults, with youth underestimating recovery needed (Brownstein et al., 2018; Gibson et al., 2017; McEwan et al., 2018).

In this study, it was found participants actual movement time (high intensity running) was only 36.94% in the feedback condition and 36.64% in the no-feedback condition of the overall exercise task. This equates to just over one quarter of the task. This is similar to (Gibson et al., 2018) study on movement characteristics in youth soccer players which found the percentage of time above maximal aerobic speed was 39.8%. These findings may be useful for practitioners for prescribing training loads for youth invasion games players.

3.4.4 – How Does Maturity Impact EF and Pacing Capacity?

Interestingly the study did not find any correlation between biological maturity and pacing. It was expected that those participants that were more biologically mature would produce both a superior IGT and pacing performance; this seemed not to be the case.

Previous research suggested that pacing ability improves with age and intellectual development (Micklewright et al., 2012). With the further along the intellectual development the better young people are able to pace (Micklewright et al., 2012). It was therefore thought that those participants that were older would show a stronger IGT performance and therefore would show the greatest ability to distribute effort during the running task, this was not proven in the current study. This data goes against previous research which has shown that cognitive development and physical maturation impacts young people's ability to pace during a high intensity intermittent running task (Brownstein et al., 2018).

It is important to note that maturity in this study was measured via biological markers not cognitive ones; some children may be further along in biological terms but lacking in cognitive and vis versa.

4.2 Conclusion

The primary aim of the present thesis was to examine the influence of EF and feedback on pacing ability. The results of the study presented in chapter 3 display that EF was found not to impact a young person's ability to plan and distribute effort effectively during a high intensity intermittent running task. It was found that when participants were provided with external feedback during the self-paced running task that performance was significantly greater than during the non-feedback condition with a greater percentage of successful runs in each of the four quarters of the feedback conditions compared to the non-feedback condition. Furthermore, it was found that one piece of feedback given early on in a prolonged task is just as effective as continuous feedback given throughout a task. The results of this study demonstrating that after the first piece of external feedback given in the running task, performance did not significantly improve after further bouts of feedback.

The results of this study are in contrast to those studies which have investigated the effect of EF on sporting performance (Verburgh et al., 2014; Vestberg et al., 2012) These studies found that participants EF ability was a good predictor of performance in ball sports, such as football. However, these studies used measurements of sporting performance that were very general such as goals scored, and assists made (Vestberg et al., 2012). Whereas the results in this study show the effect of EF has on one specific domain of match-play: pacing. Pacing is just one piece of the puzzle/skill involved in match-play, others may include: ball skills i.e. shooting and tackling, being aware of opposition positions and the ability to know when to make a tackle or pass etc. All of which could be influenced by a players EF ability.

This study also looked into the impact of external feedback on pacing ability, finding it had a positive impact on pacing performance. This corresponds with previous research, which suggests that running performance decreases without feedback (Faulkner et al., 2011), with athletes running at a lower intensity when external feedback is not present (Faulkner et al., 2011). The results are congruent with previous research showing that participants can adjust their pacing template after one piece of performance feedback (Lambrick et al., 2013).

A secondary aim of this study was to assess the influence of biological maturation on EF and pacing performance. Despite previous research showing a link between intellectual ability and pacing performance (Micklewright et al., 2012), this was not seen in the results of the current study. No link was found between EF capabilities and an increased ability to pace effectively. There may be a reason for this, one of which is that biological maturity was measured in the study and not cognitive maturity. It is unknown if participants who were physically more mature, also had an increased mental capacity.

While the results of this study did not show the hypothesised link between EF ability and pacing ability in youth athletes, it is still plausible to investigate further. One of the limitations of this study and others in this area is the lack of a standardised test of EF. Therefore, it is possible that with development of a standardised test that a link may be found between EF and specific domains of match-play in invasion sports. It may also be plausible that a player's off pitch EF ability does not correlate with there on pitch performance but with a test specific to their sport a link may be found. More research is needed to establish what the cognitive-emotional basis of performance are, as it can be deduced that physical skills are not the only things that impact sporting performance.

4.1 - Practical Implications for Future Research

In terms of practical application, the results in the present thesis suggest that young people respond best when given external feedback during an extended bout of high intensity intermittent exercise; one piece of external feedback given at the beginning of a task is sufficient. As such, the addition of external feedback during a prolonged exercise task by coaches is encouraged to improve performance. During a match-play setting where the opportunity to give regular external feedback is much less than in practice settings, these results suggest that even if a player only gets one piece of feedback early on in a game performance can be significantly improved.

Even though this study's results did not show any correlation between EF and pacing performance, future research is warranted. Given that participants in this study were only given one test of EF (the IGT) and only one chance to perform it, means that a comprehensive picture of each participant's EF may not have been available. Comparisons can be seen between pacing performance and the IGT but with no significant results attained in this study, a conclusion cannot be drawn that EF impacts pacing performance. An interesting area for future research may be to find or create a test of EF that taps into all domains, which would enable a better picture of each participants EF capabilities. After an EF profile has been built it can be compared to performance in sporting activities/movements which are present in invasion games such as pacing during a high intensity intermittent activity.

CHAPTER 5 – REFERENCE LIST

Abbiss, C. R., & Laursen, P. B. (2008). Describing and Understanding Pacing Strategies during Athletic Competition. *Sports medicine., 38*(3), 239-252. doi:10.2165/00007256-200838030-00004

Abbott, A., & Collins, D. (2004). Eliminating the dichotomy between theory and practice in talent identification and development: considering the role of psychology. *Journal of sports sciences., 22*(5), 395-408. doi:10.1080/02640410410001675324

Adams, J. A. (1971). A Closed- Loop Theory of Motor Learning. *Journal of Motor Behavior, 3*(2), 111-150. doi:10.1080/00222895.1971.10734898

Albertus, Y., Tucker, R., Gibson, A. S. C., Lambert, E. V., Hampson, D. B., & Noakes, T. D. (2005). Effect of Distance Feedback on Pacing Strategy and Perceived Exertion during Cycling. *Medicine & science in sports & exercise., 37*(3), 461-468. doi:10.1249/01.MSS.0000155700.72702.76

Almy, B., Kuskowski, M., Malone, S. M., Myers, E., & Luciana, M. (2018). A longitudinal analysis of adolescent decision-making with the Iowa Gambling Task. *Developmental psychology., 54*(4), 689-702. doi:10.1037/dev0000460

Alves, H., Voss, M. W., Boot, W. R., Deslandes, A., Cossich, V., Salles, J. I., & Kramer, A. F. (2013). Perceptual-cognitive expertise in elite volleyball players. *Frontiers in psychology, 4*, 36. doi:10.3389/fpsyg.2013.00036

Anderson, P. (2002). Assessment and development of executive function (EF) during childhood. *Child Neuropsychol., 8*(2), 71-82.

Anderson, J. R. (2011). Cognitive psychology and its applications (7th ed.). New York: Worth Publishers.

Anderson, V., Jacobs, R., & Anderson, P. J. (2008). *Executive functions and the frontal lobes : a lifespan perspective*. New York: New York : Taylor & Francis.

Anderson, V. A., Anderson, P., Northam, E., Jacobs, R., & Catroppa, C. (2001). Development of Executive Functions Through Late Childhood and Adolescence in an Australian Sample. *Developmental neuropsychology, 20*(1), 385-406. doi:10.1207/S15326942DN2001_5

Ansley, L. E. S., Robson, P. J., Gibson, A. S. C., & Noakes, T. D. (2004). Anticipatory Pacing Strategies during Supramaximal Exercise Lasting Longer than 30 s. *Medicine & science in sports & exercise., 36*(2), 309-314. doi:10.1249/01.MSS.0000113474.31529.C6

Baddeley, A. D. (1983). Working Memory. *Philosophical transactions of the Royal Society of London., 302*(1110), 311-324. doi:10.1098/rstb.1983.0057

Baddeley, A. D., & Hitch, G. (1974). Working Memory. *The psychology of learning and motivation : advances in research and theory., 8,* 47-89. doi:10.1016/S0079-7421(08)60452-1

info:doi/10.1016/S0079-7421(08)60452-1

Baden, D. A., McLean, T. L., Tucker, R., Noakes, T. D., & St Clair Gibson, A. (2005). Effect of anticipation during unknown or unexpected exercise duration on rating of perceived exertion, affect, and physiological function. *British journal of sports medicine., 39*(10), 742-746; discussion 742. doi:10.1136/bjsm.2004.016980

Bangsbo, J., Iaia, F., & Krustrup, P. (2008). The Yo-Yo Intermittent Recovery Test. *Sports Medicine, 38*(1), 37-51. doi:10.2165/00007256-200838010-00004

Baron, B., Deruelle, F., Moullan, F., Dalleau, G., Verkindt, C., & Noakes, T. D. (2009). The eccentric muscle loading influences the pacing strategies during repeated downhill sprint intervals. *European journal of applied physiology., 105*(5), 749-757. doi:10.1007/s00421-008-0957-6

Baron, B., Moullan, F., Deruelle, F., & Noakes, T. D. (2011). The role of emotions on pacing strategies and performance in middle and long duration sport events. *British journal of sports medicine., 45*(6), 511-517. doi:10.1136/bjsm.2009.059964

Basso, D., & Olivetti Belardinelli, M. (2006). The role of the feedforward paradigm in cognitive psychology. *Cognitive processing., 7*(2), 73-88. doi:10.1007/s10339-006-0034-1

Bechara, A., Damasio, A. R., Damasio, H., & Anderson, S. W. (1994). Insensitivity to future consequences following damage to human prefrontal cortex. *Cognition., 50*(1-3), 7-15. doi:10.1016/0010-0277(94)90018-3

Best, J. R., & Miller, P. H. (2010). A Developmental Perspective on Executive Function. *Child development., 81*(6), 1641-1660. doi:10.1111/j.1467-8624.2010.01499.x

Billaut, F., Bishop, D. J., Schaerz, S., & Noakes, T. D. (2011). Influence of Knowledge of Sprint Number on Pacing during Repeated-Sprint Exercise. *Medicine & science in sports & exercise., 43*(4), 665-672. doi:10.1249/MSS.0b013e3181f6ee3b

Bradley, P. S., Mohr, M., Bendiksen, M., Randers, M. B., Flindt, M., Barnes, C., . . . Krustrup, P. (2011). Sub-maximal and maximal Yo–Yo intermittent endurance test level 2: heart rate response, reproducibility and application to elite soccer. *European journal of applied physiology., 111*(6), 969-978. doi:10.1007/s00421-010-1721-2

Bradley, P. S., & Noakes, T. D. (2013). Match running performance fluctuations in elite soccer: Indicative of fatigue, pacing or situational influences? *Journal of sports sciences., 31*(15), 1627-1638. doi:10.1080/02640414.2013.796062

Brownstein, C. G., Ball, D., Micklewright, D., & Gibson, N. V. (2018). The Effect of Maturation on Performance During Repeated Sprints With Self-Selected Versus Standardized Recovery Intervals in Youth Footballers. *Pediatric exercise science, 30*(4), 500-505. doi:10.1123/pes.2017-0240

Buchheit, M., Mendez-Villanueva, A., Simpson, B. M., & Bourdon, P. C. (2010). Repeated-sprint sequences during youth soccer matches. *International journal of sports medicine, 31*(10), 709-716.

Burgess, P. W., Alderman, N., Forbes, C., Costello, A., M-Acoates, L., Dawson, D. R., . . . Channon, S. (2006). The case for the development and use of "ecologically valid" measures of executive function in experimental and clinical neuropsychology. *Journal of the International Neuropsychological Society., 12*(2), 194-209. doi:10.1017/S1355617706060310

Cahill, N., Lamb, K., Worsfold, P., Headey, R., & Murray, S. (2013). The movement characteristics of English Premiership rugby union players. *Journal of Sports Sciences, 31*(3), 229-237. doi:10.1080/02640414.2012.727456

Case, R. (1992). The role of the frontal lobes in the regulation of cognitive development. *Brain and cognition., 20*(1), 51-73. doi:10.1016/0278-2626(92)90061-P

Castagna, C., Abt, G., Manzi, V., Annino, G., Padua, E., & D'ottavio, S. (2008). Effect of Recovery Mode on Repeated Sprint Ability in Young Basketball Players. *Journal of Strength and Conditioning Research, 22*(3), 923-929. doi:10.1519/JSC.0b013e31816a4281

Castagna, C. B. C., Impellizzeri, C. B. F., Cecchini, C. B. E., Rampinini, C. B. E., & Alvarez, C. B. J. (2009). Effects of Intermittent-Endurance Fitness on Match Performance in Young Male Soccer Players. *Journal of Strength and Conditioning Research, 23*(7), 1954-1959. doi:10.1519/JSC.0b013e3181b7f743

Castagna, C. C., Manzi, C. V., Impellizzeri, C. F., Weston, C. M., & Barbero Alvarez, C. J. (2010). Relationship Between Endurance Field Tests and Match Performance in Young Soccer Players. *Journal of Strength and Conditioning Research, 24*(12), 3227-3233. doi:10.1519/JSC.0b013e3181e72709

Chinnasamy, C., St Clair Gibson, A., & Micklewright, D. (2013). Effect of Spatial and Temporal Cues on Athletic Pacing in Schoolchildren. *Medicine & Science in Sports & Exercise, 45*(2), 395-402. doi:10.1249/MSS.0b013e318271edfb

Collette, F., Hogge, M., Salmon, E., & Van der Linden, M. (2006). Exploration of the neural substrates of executive functioning by functional neuroimaging. *Neuroscience : an international journal under the editorial direction of IBRO., 139*(1), 209-221. doi:10.1016/j.neuroscience.2005.05.035

Cona, G., Cavazzana, A., Paoli, A., Marcolin, G., Grainer, A., Bisiacchi, P. S., & di Pellegrino, G. (2015). It’s a Matter of Mind! Cognitive Functioning Predicts the Athletic Performance in Ultra-Marathon Runners. *PloS one., 10*(7), e0132943. doi:10.1371/journal.pone.0132943

Denckla, M. B. (1996). A theory and model of executive function: A neuropsychological perspective.

Diamond, A. (2006). The early development of executive functions. *Lifespan cognition :, 210*, 70.

Diamond, A. (2013). Executive Functions. *Annu. Rev. Psychol., 64*(1), 135-168. doi:10.1146/annurev-psych-113011-143750

Diamond, A., & Goldman-Rakic, P. S. (1989). Comparison of human infants and rhesus monkeys on Piaget's AB task: evidence for dependence on dorsolateral prefrontal cortex. *Experimental brain research., 74*(1), 24. doi:10.1007/BF00248277

Diamond, A., & Lee, K. (2011). Interventions shown to aid executive function development in children 4 to 12 years old. *Science., 333*(6045), 959-964. doi:10.1126/science.1204529

Duffield, R., Coutts, A. J., & Quinn, J. (2009). Core temperature responses and match running performance during intermittent-sprint exercise competition in warm conditions. *Journal of strength and conditioning research, 23*(4), 1238-1244. doi:10.1519/JSC.0b013e318194e0b1

Edwards, A., & Polman, R. (2012). *Pacing in sport and exercise: a psychophysiological perspective*: Nova Science Publishers.

Edwards, A. M., Bentley, M. B., Mann, M. E., & Seaholme, T. S. (2011). Self-pacing in interval training: A teleoanticipatory approach. *Psychophysiology., 48*(1), 136-141. doi:10.1111/j.1469-8986.2010.01034.x

Edwards, A. M., & Polman, R. C. J. (2013). Pacing and Awareness: Brain Regulation of Physical Activity. *Sports medicine., 43*(11), 1057-1064. doi:10.1007/s40279-013-0091-4

Elferink-Gemser, M. T., Visscher, C., van Duijn, M. A. J., & Lemmink, K. A. P. M. (2006). Development of the interval endurance capacity in elite and sub-elite youth field hockey players. *British journal of sports medicine., 40*(4), 340-345. doi:10.1136/bjsm.2005.023044

Eston, R. (2009). What Do We Really Know about Children's Ability to Perceive Exertion? Time to Consider the Bigger Picture. *Pediatric exercise science, 21*(4), 377-383. doi:10.1123/pes.21.4.377

Faulkner, J., Arnold, T., & Eston, R. (2011). Effect of accurate and inaccurate distance feedback on performance markers and pacing strategies during running. *Scandinavian journal of medicine & science in sports., 21*(6), e176-e183. doi:10.1111/j.1600-0838.2010.01233.x

Foster, C., Schrager, M., Snyder, A. C., & Thompson, N. N. (1994). Pacing strategy and athletic performance. *Sports medicine., 17*(2), 77-85. doi:10.2165/00007256-199417020-00001

Gibson, N., Brownstein, C., Ball, D., & Twist, C. (2017). Physiological, Perceptual and Performance Responses Associated With Self-Selected Versus Standardized Recovery Periods During a Repeated Sprint Protocol in Elite Youth Football Players: A Preliminary Study. *Pediatric exercise science, 29*(2), 186. doi:10.1123/pes.2016-0130

Gibson, N. V., Henning, G., & Twist, C. (2018). Movement characteristics, physiological and perceptual responses of elite standard youth football players to different high intensity running drills. *Science and Medicine in Football, 2*(4), 281-287. doi:10.1080/24733938.2018.1461235

Glaister, M., Howatson, G., Pattison, J. R., & McInnes, G. (2008). The reliability and validity of fatigue measures during multiple-sprint work: an issue revisited. *Journal of strength and conditioning research, 22*(5), 1597-1601. doi:10.1519/JSC.0b013e318181ab80

Glaister, M., Witmer, C., Clarke, D. W., Guers, J. J., Heller, J. L., & Moir, G. L. (2010). Familiarization, Reliability, and Evaluation of a Multiple Sprint Running Test

Using Self-Selected Recovery Periods. *Journal of strength and conditioning research., 24*(12), 3296-3301. doi:10.1519/JSC.0b013e3181bac33c

Hettinga, F. J., De Koning, J. J., Schmidt, L. J. I., Wind, N. A. C., Macintosh, B. R., & Foster, C. (2011). Optimal pacing strategy: from theoretical modelling to reality in 1500-m speed skating. *British journal of sports medicine., 45*(1), 30-35. doi:10.1136/bjsm.2009.064774

Hill, A. V., & Lupton, H. (1923). Muscular exercise, lactic acid, and the supply and utilization of oxygen. *QJM: An International Journal of Medicine*, (62), 135-171.

Huizinga, M., Dolan, C. V., & van der Molen, M. W. (2006). Age-related change in executive function: Developmental trends and a latent variable analysis. *Neuropsychologia., 44*(11), 2017-2036. doi:10.1016/j.neuropsychologia.2006.01.010

Hulin, B. T., Gabbett, T. J., Kearney, S., & Corvo, A. (2015). Physical Demands of Match Play in Successful and Less-Successful Elite Rugby League Teams. *International journal of sports physiology and performance, 10*(6), 703. doi:10.1123/ijspp.2014-0080

Ingebrigtsen, I. J., Shalfawi, I. S. A., Tønnessen, I. E., Krustrup, I. P., & Holtermann, I. A. (2013). Performance Effects of 6 Weeks of Aerobic Production Training in Junior Elite Soccer Players. *Journal of Strength and Conditioning Research, 27*(7), 1861-1867. doi:10.1519/JSC.0b013e31827647bd

Jacobs, R., Harvey, A. S., & Anderson, V. (2011). Are executive skills primarily mediated by the prefrontal cortex in childhood? Examination of focal brain lesions in childhood. *Cortex : a journal devoted to the study of the nervous system and behavior., 47*(7), 808-824. doi:10.1016/j.cortex.2010.06.002

Jacobson, J., & Matthaeus, L. (2014). Athletics and executive functioning: How athletic participation and sport type correlate with cognitive performance. *Psychology of sport and exercise., 15*(5), 521-527. doi:10.1016/j.psychsport.2014.05.005

Jeffreys, I. (2006). Warm up revisited–the ‘ramp’method of optimising performance preparation. *UKSCA J, 6*, 15-19.

Jennings, D., Cormack, S. J., Coutts, A. J., & Aughey, R. J. (2012). GPS analysis of an international field hockey tournament. *International journal of sports physiology and performance, 7*(3), 224. doi:10.1123/ijspp.7.3.224

Joseph, T., Johnson, B., Battista, R. A., Wright, G., Dodge, C., Porcari, J. P., . . . Foster, C. (2008). Perception of fatigue during simulated competition. *Medicine &*

science in sports & exercise., 40(2), 381-386. doi:10.1249/mss.0b013e31815a83f6

Kerr, A., & Zelazo, P. D. (2004). Development of “hot” executive function: The children’s gambling task. *Brain and cognition., 55*(1), 148-157. doi:10.1016/S0278-2626(03)00275-6

Krustrup, P., Mohr, M., Amstrup, T., Rysgaard, T., Johansen, J., Steensberg, A., . . . Bangsbo, J. (2003). The Yo-Yo Intermittent Recovery Test: Physiological Response, Reliability, and Validity. *Medicine & science in sports & exercise., 35*(4), 697-705. doi:10.1249/01.MSS.0000058441.94520.32

Lambert, E. V., St Clair Gibson, A., & Noakes, T. D. (2005). Complex systems model of fatigue: integrative homoeostatic control of peripheral physiological systems during exercise in humans. *British journal of sports medicine., 39*(1), 52-62. doi:10.1136/bjsm.2003.011247

Lambrick, D., Rowlands, A., Rowland, T., & Eston, R. (2013). Pacing Strategies of Inexperienced Children during Repeated 800 m Individual Time-Trials and Simulated Competition. *Pediatric exercise science, 25*(2), 198-211. doi:10.1123/pes.25.2.198

Lidor, R., Côté, J., & Hackfort, D. (2009). ISSP position stand: To test or not to test? The use of physical skill tests in talent detection and in early phases of sport development. *International journal of sport and exercise psychology., 7*(2), 131-146. doi:10.1080/1612197X.2009.9671896

Lima-Silva, A. E., Bertuzzi, R. C. M., Pires, F. O., Barros, R. V., Gagliardi, J. F., Hammond, J., . . . Bishop, D. J. (2010). Effect of performance level on pacing strategy during a 10-km running race. *European journal of applied physiology., 108*(5), 1045-1053. doi:10.1007/s00421-009-1300-6

Luna, B., & Sweeney, J. A. (2001). Studies of Brain and Cognitive Maturation Through Childhood and Adolescence: A Strategy for Testing Neurodevelopmental Hypotheses. *Schizophrenia bulletin /, 27*(3), 443-455. doi:10.1093/oxfordjournals.schbul.a006886

Magill, R. A. (1994). The Influence of Augmented Feedback on Skill Learning Depends on Characteristics of the Skill and the Learner. *Quest, 46*(3), 314-327. doi:10.1080/00336297.1994.10484129

Mann, D. T. Y., Williams, A. M., Ward, P., & Janelle, C. M. (2007). Perceptual-Cognitive Expertise in Sport: A Meta-Analysis. *Journal of sport & exercise psychology, 29*(4), 457-478. doi:10.1123/jsep.29.4.457

Marcora, S. M. (2008). Do we really need a central governor to explain brain regulation of exercise performance? *European journal of applied physiology., 104*(5), 929-931. doi:10.1007/s00421-008-0818-3

Marino, F. E., Lambert, M. I., & Noakes, T. D. (2004). Superior performance of African runners in warm humid but not in cool environmental conditions. *Journal of applied physiology., 96*(1), 124-130. doi:10.1152/japplphysiol.00582.2003

Martens, R. (1977). Sport Competition Anxiety Test. Champaign, IL, England: Human Kinetics Publishers.

Mauger, A. R., Jones, A. M., & Williams, C. A. (2010). Influence of exercise variation on the retention of a pacing strategy. *European journal of applied physiology., 108*(5), 1015-1023. doi:10.1007/s00421-009-1308-y

McEwan, G., Arthur, R., Phillips, S. M., Gibson, N. V., & Easton, C. (2018). Interval running with self-selected recovery: Physiology, performance, and perception. *European journal of sport science : EJSS., 18*(8), 1058-1067. doi:10.1080/17461391.2018.1472811

McMorris, T., & Graydon, J. (1996). The Effect of Exercise on the Decision-Making Performance of Experienced and Inexperienced Soccer Players. *Research quarterly for exercise and sport., 67*(1), 109-114. doi:10.1080/02701367.1996.10607933

Meckel, Y., Machnai, O., & Eliakim, A. (2009). Relationship Among Repeated Sprint Tests, Aerobic Fitness, and Anaerobic Fitness in Elite Adolescent Soccer Players. *Journal of Strength and Conditioning Research, 23*(1), 163-169. doi:10.1519/JSC.0b013e31818b9651

Micklewright, D., Angus, C., Suddaby, J., St Clair Gibson, A., Sandercock, G., & Chinnasamy, C. (2012). Pacing Strategy in Schoolchildren Differs with Age and Cognitive Development. *Medicine & Science in Sports & Exercise, 44*(2), 362-369. doi:10.1249/MSS.0b013e31822cc9ec

Micklewright, D., Papadopoulou, E., Swart, J., & Noakes, T. (2010). Previous experience influences pacing during 20 km time trial cycling. *British journal of sports medicine., 44*(13), 952-960. doi:10.1136/bjsm.2009.057315

Miyake, A., Friedman, N. P., Emerson, M. J., Witzki, A. H., Howerter, A., & Wager, T. D. (2000). The Unity and Diversity of Executive Functions and Their Contributions to Complex “Frontal Lobe” Tasks: A Latent Variable Analysis. *Cognitive psychology., 41*(1), 49-100. doi:10.1006/cogp.1999.0734

Mohr, M., Krustrup, P., & Bangsbo, J. (2003). Match performance of high-standard soccer players with special reference to development of fatigue. *Journal of sports sciences., 21*(7), 519-528. doi:10.1080/0264041031000071182

Mussey, J. L., Travers, B. G., Klinger, L. G., & Klinger, M. R. (2015). Decision-Making Skills in ASD: Performance on the Iowa Gambling Task. *Autism research., 8*(1), 105-114. doi:10.1002/aur.1429

Nikolopoulos, V., Arkinstall, M. J., & Hawley, J. A. (2001). Pacing strategy in simulated cycle time-trials is based on perceived rather than actual distance. *Journal of science and medicine in sport /, 4*(2), 212-219. doi:10.1016/S1440-2440(01)80031-1

Noakes, T. D. (2012). Fatigue is a Brain-Derived Emotion that Regulates the Exercise Behavior to Ensure the Protection of Whole Body Homeostasis. *Frontiers in physiology., 3*, 82. doi:10.3389/fphys.2012.00082

Noakes, T. D., St Clair Gibson, A., & Lambert, E. V. (2005). From catastrophe to complexity: a novel model of integrative central neural regulation of effort and fatigue during exercise in humans: summary and conclusions. *British journal of sports medicine., 39*(2), 120-124. doi:10.1136/bjsm.2003.010330

Ozonoff, S., Pennington, B. F., & Rogers, S. J. (1991). Executive function deficits in high-functioning autistic individuals: relationship to theory of mind. *Journal of child Psychology and Psychiatry*, *32*(7), 1081-1105.

Pearson, D. T., Naughton, G. A., & Torode, M. (2006). Predictability of physiological testing and the role of maturation in talent identification for adolescent team sports. *Journal of Science and Medicine in Sport, 9*(4), 277-287. doi:10.1016/j.jsams.2006.05.020

Phillips, S. (2014). Over-estimation of required recovery time during repeated sprint exercise with self-regulated recovery. *Phillips , S 2014 , ' Over-estimation of required recovery time during repeated sprint exercise with self-regulated recovery ' vol. 28 , no. 12 , pp. 3385–3392*

Piaget, J. (1976). Piaget's theory. In *Piaget and his school* (pp. 11-23). Springer, Berlin, Heidelberg.

Piaget, J. (1974). The future of developmental child psychology. *A Multidisciplinary Research Publication, 3*(2), 87-93. doi:10.1007/BF02215168

Rauch, H. G. L., St Clair Gibson, A., Lambert, E. V., & Noakes, T. D. (2005). A signalling role for muscle glycogen in the regulation of pace during prolonged exercise. *British journal of sports medicine., 39*(1), 34-38. doi:10.1136/bjsm.2003.010645

Rl, M. (2002). An assessment of maturity from anthropometric measurements. *Medicine & science in sports & exercise., 34*(4), 689.

Smith, D. G., Xiao, L., & Bechara, A. (2012). Decision making in children and adolescents: Impaired Iowa Gambling Task performance in early adolescence. *Developmental psychology., 48*(4), 1180-1187. doi:10.1037/a0026342

Smits, B. L. M., Pepping, G.-J., & Hettinga, F. J. (2014). Pacing and Decision Making in Sport and Exercise: The Roles of Perception and Action in the Regulation of Exercise Intensity. *Sports medicine., 44*(6), 763-775. doi:10.1007/s40279-014-0163-0

Smits, B. L. M., Polman, R. C. J., Otten, B., Pepping, G.-J., & Hettinga, F. J. (2016). Cycling in the Absence of Task-Related Feedback: Effects on Pacing and Performance. *Frontiers in physiology., 7*, 348. doi:10.3389/fphys.2016.00348

Spencer, M., Bishop, D., Dawson, B., & Goodman, C. (2005). Physiological and Metabolic Responses of Repeated- Sprint Activities. *Sports Medicine, 35*(12), 1025-1044. doi:10.2165/00007256-200535120-00003

St Clair Gibson, A., Lambert, E. V., Rauch, L. H. G., Tucker, R., Baden, D. A., Foster, C., & Noakes, T. D. (2006). The Role of Information Processing Between the Brain and Peripheral Physiological Systems in Pacing and Perception of Effort. *Sports medicine., 36*(8), 705-722. doi:10.2165/00007256-200636080-00006

St Clair Gibson, A., Schabort, E. J., & Noakes, T. D. (2001). Reduced neuromuscular activity and force generation during prolonged cycling. *American journal of physiology., 281*(1), R187-R196. doi:10.1152/ajpregu.2001.281.1.R187

Steinberg, L. (2005). Cognitive and affective development in adolescence. *Trends in cognitive sciences., 9*(2), 69-74. doi:10.1016/j.tics.2004.12.005

Supekar, K., Menon, V., & Sporns, O. (2012). Developmental Maturation of Dynamic Causal Control Signals in Higher-Order Cognition: A Neurocognitive Network Model. *PLoS computational biology., 8*(2), e1002374. doi:10.1371/journal.pcbi.1002374

Swain, D. P. (1997). A model for optimizing cycling performance by varying power on hills and in wind. *Medicine & science in sports & exercise., 29*(8), 1104-1108.

Sykes, D., Twist, C., Nicholas, C., & Lamb, K. (2011). Changes in locomotive rates during senior elite rugby league matches. *Journal of sports sciences., 29*(12), 1263-1271. doi:10.1080/02640414.2011.582507

Taatgen, N. A. (2013). The nature and transfer of cognitive skills. *The psychological review., 120*(3), 439-471. doi:10.1037/a0033138

Tamm, L., Menon, V., & Reiss, A. L. (2002). Maturation of Brain Function Associated With Response Inhibition. *Journal of the American Academy of Child & Adolescent Psychiatry., 41*(10), 1231-1238. doi:10.1097/00004583-200210000-00013

Thompson K (2014). Pacing: Individual Strategies for Optimal Performance. United States of America: Human Kinetics. 27-45.

Trommer, B. L., Hoeppner, J. A. B., Lorber, R., & Armstrong, K. J. (1988). The Go—No-Go paradigm in attention deficit disorder. *Annals of Neurology, 24*(5), 610-614. doi:10.1002/ana.410240504

Tucker, J. S., Sinclair, R. R., Mohr, C. D., Adler, A. B., Thomas, J. L., & Salvi, A. D. (2008). A temporal investigation of the direct, interactive, and reverse relations between demand and control and affective strain. *Work and stress., 22*(2), 81-95. doi:10.1080/02678370802190383

Tucker, R. (2004). Impaired exercise performance in the heat is associated with an anticipatory reduction in skeletal muscle recruitment. *Pflügers Archiv European journal of physiology., 448*, 422-430.

Tucker, R. (2009a). The anticipatory regulation of performance: the physiological basis for pacing strategies and the development of a perception-based model for exercise performance. *British journal of sports medicine., 43*(6), 392-400. doi:10.1136/bjsm.2008.050799

Tucker, R. (2009b). The physiological regulation of pacing strategy during exercise: a critical review. *British journal of sports medicine., 43*(6).

Tuvblad, C., Gao, Y., Wang, P., Raine, A., Botwick, T., & Baker, L. A. (2013). The genetic and environmental etiology of decision-making: A longitudinal twin study. *Journal of adolescence., 36*(2), 245-255. doi:10.1016/j.adolescence.2012.10.006

Ulmer, H. V. (1986). Perceived exertion as a part of a feedback system and its interaction with tactical behaviour in endurance sports. *The perception of exertion in physical work* (pp. 317-326). Palgrave Macmillan, London.

Unsworth, N., Miller, J. D., Lakey, C. E., Young, D. L., Meeks, J. T., Campbell, W. K., & Goodie, A. S. (2009). Exploring the Relations Among Executive Functions, Fluid Intelligence, and Personality. *Journal of individual differences., 30*(4), 194-200. doi:10.1027/1614-0001.30.4.194

Vaeyens, R., Lenoir, M., Williams, A. M., & Philippaerts, R. M. (2008). Talent Identification and Development Programmes in Sport. *Sports medicine.*, *38*(9), 703-714. doi:10.2165/00007256-200838090-00001

Vaeyens, R., Malina, R. M., Janssens, M., Van Renterghem, B., Bourgois, J., Vrijens, J., & Philippaerts, R. M. (2006). A multidisciplinary selection model for youth soccer: the Ghent Youth Soccer Project. *British journal of sports medicine.*, *40*(11), 928-934; discussion 934. doi:10.1136/bjsm.2006.029652

Vandendriessche, J., Vaeyens, R., Vandorpe, B., Lenoir, M., Lefevre, J., & Philippaerts, R. (2012). Biological maturation, morphology, fitness, and motor coordination as part of a selection strategy in the search for international youth soccer players (age 15–16 years). *Journal of Sports Sciences*, *30*(15), 1695-1703. doi:10.1080/02640414.2011.652654

Verburgh, L., Scherder, E. J. A., van Lange, P. A. M., Oosterlaan, J., & Perales, J. C. (2014). Executive Functioning in Highly Talented Soccer Players. *PLoS ONE*, *9*(3). doi:10.1371/journal.pone.0091254

Vestberg, T., Gustafson, R., Maurex, L., Ingvar, M., & Petrovic, P. (2012). Executive Functions Predict the Success of Top- Soccer Players (Executive Functions Predict the Sport Success). *PLoS ONE*, *7*(4), e34731. doi:10.1371/journal.pone.0034731

Visscher, C., Elferink-Gemser, M. T., & Lemmink, K. A. P. M. (2006). Interval Endurance Capacity of Talented Youth Soccer Players. *Perceptual and motor skills.*, *102*(1), 81-86. doi:10.2466/pms.102.1.81-86

Voss, M. W., Kramer, A. F., Basak, C., Prakash, R. S., & Roberts, B. (2010). Are expert athletes 'expert' in the cognitive laboratory? A meta-analytic review of cognition and sport expertise. *Applied cognitive psychology.*, *24*(6), 812-826. doi:10.1002/acp.1588

Waldron, M., & Highton, J. (2014). Fatigue and Pacing in High-Intensity Intermittent Team Sport: An Update. *Sports medicine.*, *44*(12), 1645-1658. doi:10.1007/s40279-014-0230-6

Waldron, M., Highton, J., Daniels, M., & Twist, C. (2013). Preliminary Evidence of Transient Fatigue and Pacing during Interchanges in Rugby League. *International journal of sports physiology and performance.*, *8*(2), 157-164. doi:10.1123/ijspp.8.2.157

Ward, P., & Williams, A. M. (2003). Perceptual and Cognitive Skill Development in Soccer: The Multidimensional Nature of Expert Performance. *Journal of sport & exercise psychology, 25*(1), 93-111. doi:10.1123/jsep.25.1.93

Williams, A. M. (2000). Perceptual skill in soccer: Implications for talent identification and development. *Journal of sports sciences., 18*(9), 737-750. doi:10.1080/02640410050120113

Wood, R. L., & Rutterford, N. A. (2004). Relationships between measured cognitive ability and reported psychosocial activity after bilateral frontal lobe injury: An 18-year follow-up. *Neuropsychological rehabilitation, 14*(3), 329-350. doi:10.1080/09602010343000255

Young, W. B., Dawson, B., & Henry, G. J. (2015). Agility and Change-of-Direction Speed are Independent Skills: Implications for Training for Agility in Invasion Sports. *International Journal of Sports Science & Coaching, 10*(1), 159-169. doi:10.1260/1747-9541.10.1.159

Zelaznik, H. N. (1996). *Advances in motor learning and control*. Human Kinetics.